Indian Rev. Life Sci. 4: 169-217, 1984

ECOLOGY OF SOIL AND LITTER INHABITING ARTHROPODS*

M. VIKRAM REDDY

College of Agriculture, North Eastern Hill University, Medziphema-797 106, India

ABSTRACT 170

INTRODUCTION 171

SOIL ARTHROPODA 171

(a) Origin 171

(b) Methods of Sampling and Analysis 172

(c) Different Categories 174

(d) Population Abundance 178

(e) Relationship with Environmental Factors 188

(i) Soil moisture and relative humidity 188

(ii) Organic carbon (or matter) 189

(iii) Temperature 190

(iv) pH, salinity and conductivity 190

(v) Nitrate, available phosphate and calcium carbonate 191

(f) Food and Feeding 192

(g) Energy and Nutrient Content 193

(h) Association with other Edaphic Organisms 193

(i) Influence of Human Activites 194

LITTER ARTHROPODA 195

(a) Methods of Analysis 195

(b) Population Abundance 196

(c) Relationship with Environmental Factors 197

(d) Food and Feeding 197

(e) Energy Relationships 197

EDAPHIC ARTHROPODA OF AGRO-ECOSYSTEMS 197

(a) Wheat 198

(b) Other Cereals 198

*This review is dedicated to the memory of Prof. Dr. D.N. Raychoudhuri.

(c) Pulses 198
(d) Sugarcane 198
(e) Cotton 199
(f) Groundnut 199
(g) Other Crops 199
ROLE OF SOIL AND LITTER ARTHROPODS 199
(a) Litter Decomposition, Humification and Soil Fertility 199
(b) Role in Fungal Spore Dissemination 201
(c) Soil Aeration and Drainage 201
CONCLUSIONS 201
REFERENCES 202

ABSTRACT

The paper reviews the Indian literature on various aspects of the ecology of soil and litter inhabiting arthropods in different ecosystems. The ecology of soil and litter dwelling arthropods, in different agro-ecosystems, is emphasised. Most investigations in India are confined to studies of seasonal population fluctuation in relation to abiotic environmental factors, and very few investigations have been carried out on the arthropods *per se* which inhabit litter or their role in the soil and litter subsystem.

Dry funnel extractions, i.e. modified Berlese-Tullgren methods have been used by most of the investigators for studying the micro-arthropods. Collembola and Acari being most abundant, are recorded in maximum numbers during the rainy season and minimum in summer; moisture, temperature and organic carbon being the operationally significant key factors controlling their rise and fall in seasonal abundance. Studies on the behaviour and on the food and feeding habits of soi land litter arthropods indicate that termites are, of course, the most social, and that arthropods generally belong to various trophic levels. Some groups are phytophagous, feeding on the litter of both macro- and microphytes, some are mycophagous and still others predators.

The influence of various human activities, such as agriculture, forestry and building construction, reduced both the qualitative and quantitative composition of arthropods. Studies on termites and root-grubs, however, are emphasised more than Collembola and mites. This is largely because the former two are of direct economic importance in various agro-ecosystems. Nevertheless, the role of the latter two groups in plant litter breakdown and in other functional aspects of the ecosystem is considerable. The soil of ant hills and termitaria possess higher levels of plant nutrients, as compared to the underlying soils, indicating their role in soil fertility. On the other hand, certain mites, are known for their role in fungal spore dissemination. Ants and field crickets are known to improve the aeration and drainage capacity of some soils. Various areas in which research is needed in order to understand the structure and function of these arthropod populations, holistically, in the decomposer subsystems of various ecosystems, are identified.

INTRODUCTION

It is intended here to bring together the studies so far conducted on the structure and function of soil and litter inhabiting arthropod communities of various ecosystems of the Indian subcontinent. Besides, key roles of these arthropods in the ecosystem, such as litter breakdown, humification, soil fertility, aeration and drainage are highlighted. The functional parameters to which little attention has been paid in India are pointed out for understanding the principles of the structure and functioning of various ecosystems (Banerjee, 1974 b).

Soil and litter are two different layers of materials lying above bedrock. The former lies immediately below the latter and harbour arthropods which often move from there to the litter and *vice versa*. It is scarcely possible to separate them (Kevan, 1965). Arthropods, numerically constitute a very significant group in any ecosystem. On land, most of them occur at least temporarily in the soil and litter subsystem, as about 95 per cent of them spend at least a part of their life there (Buckle, 1921). Some of them enter it only by chance; others enter it merely to take refuge, but there are numerous true inhabitants of soil. They belong to four biological groups, according to their ability to penetrate the soil (Kühnelt, 1963), burrowing arthropods; the non-burrowing confined to the litter layer; those inhabiting the pore spaces of the soil; and arthropods inhabiting the small water filled cavities and spaces of the soil. The arthropods inhabiting the upper soil layers and litter are known as "hemiedaphic", whereas those inhabiting the deeper layers are known as "euedaphic". Animals other than arthropods also include soil and litter inhabiting species of all categories.

During the last decade, efforts have been made to bring the workers of soil zoology and ecology to a common platform, and proceedings entitled "Soil Biology and Ecology in India" (Edwards & Veeresh, 1978), "Progress in soil Biology and Ecology in India" (Veeresh, 1981) and "Contributions to Acarology", (Channa-Basavanna, 1981), have been published. The Indian Society of Soil Biology and Ecology was formed in 1976, which began publishing the international Journal of Soil Biology and Ecology in 1981. In addition, a few reviews on various aspects of edaphic arthropod coenology in India have appeared (Chhotani, 1980, 1981; Ghosh, 1981; Pal, 1977; Prabhoo, 1981; Reddy, 1981d; Roonwal, 1958, 1972, 1981; Sen-Sarma, 1974, 1981; Singh, 1978; Veeresh, 1977; and Verghese & Veeresh, 1978).

SOIL ARTHROPODA

(a) Origin

There is little information, and that too controversial, on the origins of the soil and litter arthropod fauna. The ancestors of terrestrial Isopoda and Amphipoda and of land crabs presumably found their way directly from the marine supralitoral into the surrounding terrestrial environments (Kühnelt, 1963). Freshwater animals of basically marine origin such as Amphipoda, harpacticid Copepoda, Ostracoda and certain Decapoda have all been recorded from moist places, wet meadows and forests with high rainfall. The calanoid copepods, which are usually aquatic, have also been recorded in soil and litter samples in a *Pinus kesiya* Royle, plantation near Shillong at an altitude

of *ca.* 1125 m msl (author's unpubl. data), thus showing a connecting link between aquatic and terrestrial ecosystems inhabiting arthropods.

According to Gilyarov's (1949) hypothesis ancestral insects migrated from freshwater to the dryland *via* the soil, and may have long dwelt in the latter environment, where there was little chance of desiccation. Omodeo *et al.* (1980), however, believe that the first pterygote insects appeared in the Devonian times before there was any true terrestrial system, it being scarcely credible that arthropods could have abandoned the existing aquatic systems in order to colonize a nearly non-existent soil system. Nevertheless, some of Gilyarov's concept are creditable. Undoubtedly, however, some of the soil arthropod fauna has originated from ancestors living on dryland outside the soil (Kühnelt, 1963), and which, in turn, became adapted to the soil environment. The true soil Collembola which are small, lack scale, are unpigmented,and with reduced springing organs,may have originated from the epigeic species (Reddy, 1980 a) which are generally larger, pigmented and with scales, and have larger leaping organs. Nevertheless, it is difficult to demonstrate any phylogenetic relationships for many other arthropods such as mites, centipedes and millipedes with either aquatic or the epigeic fauna.

(b) Methods of Sampling and Analysis

Investigators studying the ecology of soil-inhabiting arthropods should be very clear as to the methods they use, although the availability of funds determines the sophistication and nature of apparatus used. It is of no avail simply to extract arthropods from soil without having any purpose in mind; too many ecologists do this and waste their time (Macfadyen, A., personal communication). There is a need to develop standardised methods which can be universally adopted in order that the results be compared with greater confidence. This is, as yet, far from being achieved. If the extraction techniques are not efficient, then it is difficult to collect a representative arthropod fauna in keeping with the re ative abundance of its components. A funnel apparatus which can extract small and delicate microarthropods such as Protura, Pauropoda, Prostigmata, etc., in abundance attests to the efficiency of the extraction procedures (Price, 1973)

Soil surface-inhabiting arthropods can be studied by means of pit-fall traps. The problems of interpretation of the data gained from arthropod samples using such traps has been described by Adis (1979), but these traps, though very efficient for studying the ecology of epedaphic arthropods, and popular abroad, have been very little used in India. Indeed, very little information is available from any source regarding Indian soil surface-inhabiting arthropods (Dutta & Gupta, 1981; Oppenheimer & Tikader, 1976). Oppenheimer & Tikader, however, using pit-fall traps, studied the seasonal changes in the activity of spiders and harvestmen on the ground near Calcutta (West Bengal), and Dutta (1983) studied the seasonal activity and density of ground beetles of the Dooars area of Jalpaiguri (West Bengal). The author (unpubl), also, has studied qualitatively and quantitatively the composition and seasonal abundance of different groups of soil surface-inhabiting arthropods of different agro-ecosystems, comparing them with the adjacent forest ecosystems near Dimapur and Medziphema (Nagaland). In addition, Reddy & Tiwary (unpubl.) have studied the effect of fire

on the soil surface-inhabiting arthropods of an uncultivated area at Medziphema and Reddy & Ao (unpubl.) have investigated the effect of cultivation and building construction on such arthropods in a forested system at Medziphema. Pit-fall traps were also used with various baits, such as rotten fish and fresh cowdung, by Dutta & Gupta (1981) in order to increase the size of samples of beetles of the Dooars area.

The ecology of soil inhabiting microarthropods is usually studied by using extraction methods, which are of two basic kinds: mechanical and dynamic or behavioural (Pande, 1975), the former theoretically extracting all the stages both mobile and sedentary; the latter causing the arthropods to leave the substrate of their own accord in response to various stimuli such as heat, light, and moisture (Southwood, 1966). It is generally agreed that the latter method is more advantageous. Most workers, not only in India but also abroad, use behavioural methods of extraction (Edwards & Fletcher, 1971). One or two laboratories dealing with particular types of soil and litter arthropod studies, however, use mechanical methods of extraction, such as modified flotation methods. In India, this is examplified by Singh (1975) and Singh & Pillai (1976).

Mechanical methods of extraction involve dry sieving, soil washing (or wet sieving) and flotation, separation of plant and animal matter by differential wetting, centrifugation, sedimentation and elutriation, whereas behavioural methods involve dry extractors, such as modified Berlese-Tullgren funnels, horizontal extractors, multiple canister extractors and Kempson bowl extractors (Southwood, 1966). Singh (1975) indicated a mechanical method of extraction, such as flotation, to be more efficient than Berlese-Tullgren funnels, particularly for sandy loam and soils of lower organic matter content. The flotation method was used for the extraction of soil-inhabiting arthropods by Mukharji & Singh (1970) and by Singh & Mukharji (1971). As noted by Kühnelt (1963), however, wet (mechanical) methods of extraction tend to be rough and to damage delicate animals like Protura which lose their appendages. Thus, most workers prefer to use improved Berlese-Tullgren extraction methods which are adequately efficient and which give comparatively better results in less time.

A number of other methods have also been developed to study the arthropods and their activities under natural conditions. One of these is by preparing sections of undisturbed soils (Nicholas & Parkinson, 1967). A similar method using gelatine for impregnation and known as the gelatine-embedding technique, was earlier described by Minderman (1957). Anderson & Healey (1970) made some improvements. Pande (1975) used their improved technique intensively when studying the arthropods of a pine forest soil; he compared its efficiency with that of Tullgren funnels and concluded that the soil sectioning method is superior to core extraction methods.

Some soil arthropods such as termites, are estimated gravimetrically. In the case of termites this is done by weighing several small subsamples, counting the number of termites contained, and multiplying the number per unit weight by the total weight of the mound (Banerjee, 1966, 1971). Sen-Sarma & Mishra (1969, 1972, & 1981) estimated the populations of different species of termites volumetrically, checking and correcting the estimates with the

actual counts of small repesentative samples. Banerjee & Choudhuri (1980) used light-traps for studying the seasonal swarming activity of *Dorilus labiatus* Westw. In addition many other investigators have used light-traps for recording the activities of soil surface-inhabiting insects (Banerjee *et al.*, 1981; Patil *et al.*, 1981, Vaishampayan,1981; Veeresh & Rajanna, 1981; Reddy & Alfred, 1982).

Other larger arthropods, including insects entering the soil litter subsystem, may be counted directly *in situ* (Southwood, 1966). Larger insects, including their larvae, can also be sampled by sieving the loose soil and litter through different meshes (Kühnelt, 1963). A repellent method can also be used, for example, by applying orthodichlorobenzene emulsion to the soil surface in order to sample insect larvae (Barnes, 1941).

(c) Different Categories

Soil arthropods have been grouped into various ecological categories (Kühnelt, 1963; Kevan 1965; Hole, 1981). Kühnelt (1963) distinguished several group of arthropods inhabiting soils, one of these constructing holes by digging, and another moving through the soil within self-constructed burrows. Such animals have been reported in India (Reddy, 1980 b, 1981b). Various "water" animals are also found inhabiting the soil, although reports of such are very scanty for India. Calanoid copepods, however, have been recorded in the top soil layers of a pine plantation in north-eastern India (author's unpubl.), and various copepods and ostracods have also been reported from different upland agro-ecosystems and forested systems in Nagaland (Reddy, Ao & Tiwary, unpubl.).

Most categories of soil and litter inhabiting arthropods are seen in any balanced ecosystem. Different groups of soil arthropods recorded from various Indian ecosystems are presented in Table 1, which reveals that the number of groups recorded were maximum in north-eastern Indian ecosystems. It also indicates that the number of categories of arthropods varies from habitat to habitat, which is most probably owing to variation in vegetation and in both micro- and macro-climatic conditions. Studies dealing with the ecology of soil-surface and/or soil-inhabiting arthropods of any soil-litter subsystems are, nevertheless, virtually lacking for India. Recently, however the author has recorded both the qualitative and quantitative composition of both soil surface and soil inhabiting arthropods of different agro-ecosystems and the adjoining mixed and bamboo forests (Table 1). Such studies are needed in order to understand the holistic composition of the arthropod fauna in decomposer subsystems.

Different groups of pterygote insects, particularly Diptera, reported by various investigators often confuse counts for genuine soil-inhabiting forms, as many such insects may be attracted to the lights used in the funnel apparatus and may thus find their way into the collecting vessels. Workers should be very careful to distinguish those species attracted to light from those actually inhabiting the soil.

It should also be noted that termite as a group, have in most investigations dealing with soil-inhabiting arthropods, been neglected or underestimated in number, even though they constitute one of the most abundant groups of soil fauna. This is because the sampling methods employed in the case of termites

Table 1. Different groups of edaphic arthropods from various ecosystems in India.

Habitat & Locality		Number and different groups of arthropods	Sampling unit (cm) size and method	Reference
1		2	3	4
Cotton fields and fallowland, Lyalpur (now in Pakistan)	8	Coleoptera, Dermaptera Diptera, Hemiptera, Hymenoptera, Lepidoptera, Orthoptera and Thysanoptera	22.8x22.8x22.8 Separation by washing the soil	Trehan (1945)
Soil understones, moss, snow, etc. North-west Himalayas	7	Coleoptera, Collembola, Dermaptera, Diptera, Hymenoptera, Orthoptera and Thysanoptera	Sweeping and brushing	Mani & Singh (1955)
Unspecified habitats, different districts of West Bengal	12	Acarina, Centipeds, Coleoptera, Collembola, Diplura, Homoptera, Hymenoptera, Isopoda, Isoptera, Orthoptera, Protura, Pseudoscorpionida and other orders	Berlese-Tullgren funnel	Choudhuri & Roy (1970)
Rose gardens, Varanasi	2	Acarina and Collembola	7.6x10.16x22.86 Ladell's apparatus	Mukherji & Singh (1970)
Rose, Sugarcane, Falsa, Botanical garden and uncultivated fields, Varanasi	8	Acarina, Collembola, Diptera, Palpigrada, Pauropoda, Pseudoscorpionida, Symphyla and Uripygi	—do—	Singh & Mukherji (1971, 1973)
Deciduous forest, Varanasi	3	Acarina, Collembola and other groups	7.62x10.6x20.32, Tullgren funnel	Singh & Singh (1975)
Grassland	3	—do—	7.62x10.6x33.0 Tullgren funnel	—do—
Virgin forest and adjoining tea fields, Western Ghats (Kerala)	4	Acarina, Collembola, Protura and Symphyla	2.5x2.5x10.0 Berlese-Tullgren funnel	Prabhoo (1976)
Eroded laterite areas paddy and fodder fields and fallow grassland, Santiketan (W. Bengal)	15	Acarina Araneida, Coleoptera, Collembola, Diplura, Diptera, Hemiptera, Hymenoptera, Isopoda, Orthoptera, Ostracoda, Pseudoscorpionida, Psocoptera, Symphyla and Thysanoptera	5x5x5, Tullgren funnel	Bhattacharya & Joy (1978)
Sugarcane, Tamil Nadu	5	Homoptera, Isopoda, Isoptera, Symphyla and Coloepteran larvae	—	David (1978)
Coniferous forest, grazed and fenced area	3	Acarina, Collembola and other arthropods	10x7.5x6 Tullgren funnel	Raina *et al.* (1979)
Polluted and unpolluted pedoecosystem	3	—do—	10.6x10.6x32.5 Ladell's apparatus	Singh *et al.* (1979)

Contd...

1		2	3	4
Soil surface understone Berhampur	10	Acarina, Araneida, Chilopoda, Coleoptera, Hymenoptera, Isopoda, Isoptera, Lepidoptera larvae and Orthoptera	500x600, Visual observation	Reddy (1980 b)
Field with a cover of grass & weeds Santiniketan	5	Collembola, Hemiptera, Hymenoptera, Psocoptera and Thysanoptera	5x5x10, Tullgren funnel	Bhattacharya *et al.* (1980)
Cultivated and grassland ecosystem, Bangalore	11	Coleoptera, Collembola, Dermaptera, Diplura, Diptera, Hemiptera, Hymenoptera, Isoptera, Orthoptera, Psocoptera and Thysanoptera	Sampling unit size; not specified; Barlese-Tullgren funnel	Veeresh & Reddy (1980)
Tea nursery beds, Nagabang	6	Acarina, Coleoptera, Collembola, Diptera, Lepidopteran larvae and Protura	5x5x10 Barlese-Tullgren funnel	Reddy (1981 c)
Coniferous forest	2	Acarina and other Arthropods	7.5x10x15 Tullgren funnel	Dhar *et al.* (1981)
Banana, citrus, fodder and fallow systems, Varanasi	9	Acariana, Collembola, Japya, Palpigrada, Pseudoscorpionida, Protura, Symphyla and other arthropods	10x7.5x22.5 Ladell's apparatus	Singh & Pillai (1981)
Paddy & uncultivated fields, Kerala	4	Acarina, Collembola, Diptera and other arthropods	12.57x10 Burlese-Tullgren funnel	Pai & Prabhoo (1980)
Silent Valley, Kerala	14	Acarina, Araneida, Centipedes, Coloeptera, Collembola, Dictyoptera, Diplura, Hymenoptera, Isopoda, Isoptera, Millipedes, Orthoptera, Pseudoscorpionida and Thysanoptera	3 cm (diam.)x10 Berlese-Tullgren funnel	Hazra (1982)
Forest and Jhum fallows, Shillong	15	Acarina, Araneida, Chilopoda, Coleoptera, Collembola, Dermaptera, Diplopoda, Diplura, Diptera, Hymenoptera, Isopoda, Protura, Pseudoscorpionida, Psocoptera, and Symphyla	25x25, Tullgren funnel	Darlong & Alfred (1982)
Pine plantations, Shillong	7	Acarina, Araneida, Centipedes, Coleoptera, Collembola, Protura and Symphyla	5x5x10 Tullgren funnel	Reddy (1983 a)

Contd...

1		2	3	4
Pine plantations, Shillong	14	Acarina, Araneida, Chilopoda, Coleoptera, (adults and larvae), Collembola, Diplopoda, Diplura, Dipteran larvae, Hymenoptera, and Isopoda	5x5x10 Tullgren funnel	Reddy (unpubl.)
Upland paddy, maize and sugarcane agro-ecosystems and the adjoining forest (mixed and bamboo), Medziphema	19	Acarina, Araneida, Chilopoda, Coleoptera Collembola, Dermaptera, Dictyoptera, Diplopoda, Diptera, Hoteroptera, Homoptera, Hymenoptera, Isopoda, Isoptera, Lepidopteran adults and larvae, Orthoptera, Pseudoscorpionida, Gecarinidae and Symphyla	Pitfall traps	Reddy, Ao & Tiwary (unpubl.)
Upland paddy, maize and sugarcane agro-ecosystems and the adjoining forest (mixed and bamboo), Medziphema	18	Acari, Araneidae, Chilopoda, Copepods, Coleoptera (adults & larvae), Collembola, Diplopoda, Diplura, Diptera (larvae), Heteroptera, Hymenoptera, Isoptera, Opelionida, Orthoptera, Pauropoda, Protura, Peocoptera and Symphyla	4 dia. x 5 (depth) Berlese-Tullgren funnel	Reddy, Ao & Tiwary (unpubl.)

populations are different from those of other arthropod groups.

Among soil inhabiting arthropods, the Collembola, or springtails, and the Acari or mites, predominate. In some cases the former are more numerous than the latter, in others, *vice versa* (Mani & Singh, 1955; Choudhuri & Roy, 1967; Mukharji & Singh, 1967, 1970; Singh & Mukharji, 1971; Bhattacharya & Joy, 1978; Veeresh & Reddy, 1978; Reddy, 1981 a; Prabhoo, 1981). Singh & Mukharji (1973) observed that Collembola and Acari composed 72 to 97% of the soil arthropod fauna, and Singh & Pillai (1975) reported that Acari and Collembola combined constituted 85.2 to 92.6% of the total soil arthropods. Singh (1977) recorded 76.5% of the total soil arthropods as being Acari and Collembola, the former group being dominant. The present author (unpubl.) has found that the Collembola and Acari constituted about 95% of the total soil arthropods in a pine plantation near Shillong.

For subterranean termites, Mukherji & Mitra (1949) recorded the ratio of soldiers-workers-nymphs in *Odontotermes redemanni* (Wasmann) and found that 2.42% were soldiers, 14.25% workers, and 81.33% immature forms. Roonwal (1954) recorded the worker-soldier ratio in a related species *Odontotermes parvidens* to be 97.8 : 2.2%. For *Coptotermes heimi* (Wasmann) he reported 33% soldiers and 67% workers. Sen-Sarma & Mishra (1969) estimated that, in *Microcerotermes beesoni* Snyder, workers constituted 63.43 to 98.08% and soldiers 0.55 to 3.8% of the total population. Singh & Singh (1981 a), however, recor-

ded the average ratio of workers: soldiers: nymphs: imagos as 77.5: 4.1: 16.8: 1.7 for *Odontotermes obesus* (Rambur) and *Odontotermes redemanni* (Wasmann).

(d) Population Abundance

The population abundance of various species of hemi- and eu-edaphic arthropods have been reported by different investigators from time to time. Synecological investigations on the population abundance in different soil arthropod communities at the supra-specific level are comparatively numerous, but autecological studies and those listing species by name are not so. This is most probably because of the difficulties in species identification, one of the stumbling blocks of all ecological work, and especially applicable to the soil fauna.

Populations of different species of subterranean termites, including *Odontotermes obesus* (Ramber), *O. microdentatus* Roonwal & Sen-Sarma, *Microcerotermes beesoni* Snyder (Mukherji & Mitra, 1949; Gupta, 1952; Banerjee, 1966; Sen-Sarma & Mishra, 1969, 1972, 1981; Agarwal 1978 b; Patil *et al.*, 1981; Singh & Singh, 1981 a), of ants such as *Camponotus compressus* Fabricius, *Oecophylla smaragdina* Fabricius, *Dorilus labiatus* Schuck, and *Dorilus orientalis* Westw. (Gupta, 1963, 1964; Banerjee & Choudhuri, 1980; Patil *et al*, 1981), of the millipedes, *Allajulus* (*Cylindroiulus*) *punctatus* (Leach), *Tachypodoiulus niger* (Leach) and *Polydesmus angustus* Latzel (Banerjee, 1967 a, b), of various spiders (Oppenheimer & Tikader, 1976) and Coleoptera (Dutta & Gupta, 1981; Veeresh & Rajanna, 1981), including the white-grubs, *Holotrichia consanguinea* Blanchard (Veeresh, 1977; Yadava *et al.*, 1977, 1978; Mathur *et al.*, 1979; Sharma *et al.*, 1981; Brar & Sandhu, 1982), of crickets such as *Brachytrupes portentosus* (Lichtenstein) (Reddy, 1981 b), *Plebeiogryllus* (formerly *Platygryllus*) *guttiventris* (Walker) and *Gryllotalpa* (probably *G. orientalis* Buoveister recorded as *G. africana* Beauvois) (Patil *et al.*, 1981), and of Psocoptera, namely *Liposcelis transvallensis* Enderl (Bhattacharya, 1971) have been studied.

In addition, investigations on the population abundance of different groups of arthropods such as Collembola and Acari of various Indian habitats have been made (Singh, J. & Singh,U.R.1975; Singh,U.R. & Singh,A.K. 1975; Singh,1977; Bhattacharya & Joy,1978; Mukharji & Singh, 1970; Singh *et al.*, 1979; Raina *et al.* 1979; Vatsauliya & Alfred, 1980; Chaudhuri & Pande, 1981; Pai & Prabhoo, 1981; Dhar *et al.*, 1981; Singh & Pillai, 1981; Darlong & Alfred, 1982; and author's unpubl. data). Studies on the population abundance of different species of Acari, however, have mostly related to Cryptostigmata (Reddy, 1981 b; Singh & Pillai, 1981; Banerjee & Roy, 1981; Bhattacharya *et al*, 1981; Sanyal, 1982). Singh & Pillai (1981) reported on the population ecology of Prostigmata, Mesostigmata and Astigmata in various habitats. The population abundance of various species of Collembola for different ecosystems have also been studied (Choudhuri & Roy, 1967; Singh & Mukharji, 1971; Choudhuri & Roy,1971 a, b, 1972; Choudhuri & Banerjee, 1975; Prabhoo, 1976; Mitra *et al.*, 1977, 1978; Hazra,1978 a, b; Choudhuri *et al.*, 1978; Mukherjee & Roy, 1981; Hazra & Chaudhuri, 1981; Singh & Pillai, 1981; and author's unpubl. data).

The population size for different groups of arthropods inhabiting the upper soil layers in different ecosystems in India is given in Table

2, a perusal of which reveals that the pine forests of Meghalaya yield the maximum population of total soil arthropods in general and of Acari in particular (Darlong & Alfred, 1982) and of total Collembola (author's unpubl. data). On the other hand, minimum numbers of Collembola (Bhattacharya & Joy, 1978) and of total microarthropods (Bhattacharya *et al.*, 1981) were recorded in paddy agro-ecosystems. Similarly, Raina *et al.* (1979) recorded minimum numbers of total Acari in a grazed system. Among different groups of Acari, Cryptostigmata and Mesostigmata were recorded in maximum numbers in deciduous forest soils near Varanasi (Singh & Singh,1975), numbers for former group being minimal in paddy fields (Bhattacharya *et al.*, 1981) and for the latter groups in polluted sites (Singh *et al.*, 1979). Total numbers of arthropods other than Collembola and Acari, were recorded as being maximal in a deciduous forest (Singh & Singh, 1975) and minimal in a pine forest (author's unpubl. data). Comparisons of the population estimates given by different authors, and for different types of habitat are, however,difficult, as there is wide variation in the depths at which samples were taken. Moreover, variations in recorded populations may be due to intrinsic differences between habitats, as well as to differences in emphasis and techniques of individual workers (Price, 1973).

Although numerous investigations on the ecology of soil arthropods under varied vegetation covers exist, studies designed especially for the purpose of investigating the effect of such cover *per se* on soil arthropods are nevertheless rather scarce. Of late, the author has investigated the effect of grassy vegetation on soil surface-inhabiting arthropods by means of pit-fall traps, and has found that sites with vegetational cover supported a greater abundance of arthropods than bare sites (unpubl. data). Bhattacharya (1971), comparing the microarthropod populations under different vegetation has reported that these were maximal in *Casuarina* litter and minimal in Khowai soil Singh & Mukharji (1971, 1973) compared the abundance of different species of Acari, Collembola and other arthropods of rose garden, sugarcane, falsa, botanical garden and uncultivated systems (without vegetation) and found that the mite populations were higher in the uncultivated system, whereas Collembola were more numerous in rose garden soils. On the other hand, miscellaneous arthropods, such as Pauropoda, were relatively more abundant in the sugarcane system. Prabhoo (1976) recorded a greater abundance of soil arthropods, particularly Collembola in forests having a good undergrowth of shrubs, as compared with those which did not. Gupta & Mukherji (1976 a, b) recorded both the qualitative composition of the arthropod fauna of sunnhemp, paddy and uncultivated soil systems.

Mitra *et al.* (1977, 1978) sampled the Collembola associated with six different types of vegetation at Eden Garden (Calcutta) and reported that a site with banana plants yielded a greater number, followed successively by bamboo, *Ixora* sp., grass, *Sansevieria* sp. and drainage site. They found different species of Collembola to be dominant under different plant covers : thus *Pseudosinella* sp. was common under grass, *Megalothorax minimus* Willem in bamboo, banana and *Sansevieria* sp. systems, *Cyphoderus albinus* (Nicolet) in the *Ixora* sp. system and *Isotomina thermophilla* (Axelson) in

the drainage site. Bhattacharya & Joy (1978) recorded a variation in population densities of soil microarthropod from site to site and found maximum abundance in a fallow grassland. This was followed successively by fodder crop paddy field and an eroded laterite area. Singh *et al.* (1979) found comparatively less abundance in polluted soils. Raina *et al.* (1979) compared the soil and litter mesofauna of coniferous forest, protected (non-grazed) and grazed systems. They found the first of these to have the maximum number of arthropods followed by the protected area, the grazed system having the fewest. On the other hand, Vatsauliya & Alfred (1980), in studying the microarthropods population densites of different jhum fallows, could scarcely detect any significant difference in population abundance between 1 year and 20 years-old fallows, although the latter was supposedly nearer to the natural condition of the system. Pillai & Singh (1980) studied the composition of the soil microarthropod fauna of a grassland system, and followed this up a year later with studies of the soil fauna beneath banana, citrus and fodder crops and in fallowland. They recorded Acari as being most abundant in the first two situations, whereas the abundance of Collembola, though greatest in the banana plantation was lowest in the citrus orchard. Bhattacharya *et al.* (1981) compared the community structures of soil Cryptostigmata of grassland, *Acacia*, forest, paddy field and banana plantation, and reported that the population density varied from site to site, being maximal in the last and minimal in the paddy field. Choudhuri & Pande (1981) reported a maximum for Acari in a zoological garden site when this was compared with the Birch Hills (West Bengal). Hazra & Choudhuri (1981) found Collembola populations to be maximum in systems with comparatively greater numbers of herbs, shrubs and trees. Reddy (1981 b) recorded a greater population of a large burrowing cricket, *Branchytrupes portentosus* Lichtenstein in a roadside earth drainage system as compared with grassland. Darlong & Alfred (1982) found that forest sites showed higher arthropod density than the jhum sites. Singh & Mahajan (1983) reported Acari as most numerous group of microarthropods in the soil, while Collembola were the dominant group in the litter of a teak, *Tectona grandis* plantation. Reddy, Ao & Tiwary (unpubl.) compared the population abundance of soil micro-arthropods in maize, sugarcane and dryland paddy fields with that of an adjacent forest and found maximum populations in the latter.

Seasonal variation in population density of soil arthropods have been investigated by several workers. Monthly populations vary from season to season, and from habitat to habitat. Some species of arthropods demonstrated only single peaks of population abundance, whereas many others showed two or more such peaks per year. Bellinger (1954) suggested that single population peaks implied univoltinisus and that two or more generations per year were involved in the cause of corresponding peaks.

Sen-Sarma & Mishra (1969) studied the seasonal fluctuations in nest populations of the termite, *Microcerotermes beesoni* Snyder and reported that nymphs of alates occurred in the nest from March until June,whilst alate were found from May until July. They recorded the highest population densites of the immature workers and soldiers during April, when the

Table 2. Population size of different groups of arthropods inhabiting upper soil layers of various ecosystems in India.

Habitats	No. per sample size	Total population of arthropods	Collembola	Total Acarina	Groups (of Acarina)	Total other arthropods	Groups (of other arthropods	Reference
1	2	3	4	5	6	7	8	9
Rose gardens	No. 7.6x 10.16x22.86 cm	—	16 to 180	100-120	—	—	—	Mukherji & Singh (1970)
Cultivated and uncultivated fields	$10^3 m^{-2}$	9.45 to 16.87	—	—	—	—	—	Singh & Mukherji (1973)
Himalayan grassland	No. m^{-2}	31827.8 ±3680.8	6282.6 ±569.4	20570 ±2503.6		4975±710.3		Singh & Singh (1975)
Deciduous forest	No. m^{-2}	24868.44 ±2821.94	4604.51 ±692.13		Prostigmata+ Astigmata 228.857±29.86 Cryptostigmata 8519.965±911.32 Mesostigmata 5987.707±569.41	5527.405 ±441.14		Singh & Singh (1975)
Banana field	No. m^{-2}	—	10772	—	—	—	—	Singh & Pillai (1975)
Citrus orchard			2286					
Fodder crop			4462					
Fallow area			5146					
Forest	$10^3 m^{-2}$	—	24	—	—	Protura	4.8	Prabhoo (1976)
Forest cleared			19				1.6	
Tea field			24				3.2	
Uncultivated	—	—	1877 to 2469	—	—	—	—	Hazra *et al.* (1976)
Uncultivated	—	—	133.3 (mean of 3 years)	—	—	—	—	Hazra (1978 a)
Eroded laterite site	No. m^{-2}	—	1480	—	—	—	—	Bhattacharya & Joy (1978)
Paddy field			1640					
Fooder field			6640					
Fallow grassland			16040					
Grassland	No. m^{-2}	—	153.3 (mean of 3 years)	—	—	—	—	Choudhuri *et al.* (1978)

Contd...

1	2	3	4	5	6	7	8	9
Polluted soil	No. m^{-2}	11912	2328	—	Cryptostigmata 2732±1002 Mesostigmata 2416±413 Prostigmata+ Astigmata 1426±187	2328±1128		Singh *et al.* (1979)
Unpolluted soils	No. m^{-2}	19157 ±2841	3909 ±621	—	Cryptostigmata 4 31±813 Mesostigmata 3392±711 Prostigmata+ Astigmata 1424±187	4961±831	—	Singh *et al.* (1979)
Coniferous forest	No. m^{-2}	—	2700±101	3900±130	—	197±101	—	Raina *et al.* (1979)
Protected system			2000±932	11800 ±2700		48±14		
Grazed system				576±173		79±32		
1 year old jhum fallows	No. m^{-2}	27600	—	—	—	—	—	Vatsauliya & Alfred (1980)
5 year old jhum fallows		14800	—	—				
10 year old jhum fallows		28000	—	—				
20 year old jhum fallows		49200	—	—				
Cultivated field	—	52.46	—	—	—	—	Diplura 16.84 Protura 0.62	Veeresh & Reddy (1980)
Grass field		58.71	—	—	—	—	Diplura 9.92 Protura 0.98	
Coniferous forests	No. m^{-2}	5095.59 ±1763.23	—	—	Cryptostigmata 4500 32±1600.41 Mesostigmata 397.34±101 Prostigmata 100.98±32.55	97.27±29.19	—	Dhar *et al.* (1981)

Contd...

1	2	3	4	5	6	7	8	9
Unc. Grassland	No. 8.55 cm^2x3 cm	—	40	246	Cryptostigmata-246 30 to 60	—	—	Mitra *et al.* (1981)
Uncultivated area	No. 17.36 cm^2x5 cm	—	—	—	Cryptostigmata 30 to 60	—	—	Sanyal (1981 a)
Uncultivated area	No. 17.36 cm^2x5 cm	—	—	—	Cryptostigmata-31	—	—	Sanyal (1981 b)
Grassland	No. m^{-2}	12027	—	—	8472 Cryptostigmata-5431	—	—	Bhattacharya *et al.* (1981)
Acacia forest		5454			3342—1194			
Paddy field		4518			2597—870			
Banana plantation		17464			9871—4400			
Banana plantation	No 5x5x10 cm	—	—	—	Cryptostigmata 20 to 30	—	—	Joy & Bhattacharya (1981)
Tea nursery beds	No. m^{-2}	37733.33 ±2799.15	6000.00 ±3448.77	30266.66 ±18767.43	—	1466.66 ±352.77	Protura 266.66 ±133.33	Reddy (1981 c)
Silent valley	No. 3 cm (dia.)x10 cm (depth)	2920	715.68	—	—	—	—	Hazra (1982)
Upper Shillong jhum	No. m^{-2}	1924x10^2 892x10^2	676x10^2	688x10^2	—	—	—	Darlong & Alfred (1982)
Barapani forest jhum		1520x10^2 800x10^2	342x10^2	636x10^2				
Barnihat forest		1848x10^2	408x10^2	484x10^2				
Uncultivated area (Sugar Island)	No. 17.36 cm^2 x 5 cm	—	—	—	Cryptostigmata-31	—	—	Sanyal & Bhaduri (1982)
Pine plantation	10^2 m^{-2}	1452	1212	416	—	64	—	Reddy (unpubl.)

adult worker and soldier population was at its lowest. Agarwal (1978 b) recorded the seasonal fluctuation of *Odontotermes microdentatus* Roonwal et Sen-Sarma and *O. obesus* (Rambur) and in both, the maximum number of nymphs was found in April, adult soldiers being most numerous in December-January,and adult workers in February. Sen-Sarma & Mishra (1981) recorded the maximum population of brood in a colony of *Neotermes bosei* Snyder during August (rainy season),with a decline in April (summer), the maximum being recorded in December (winter). In *Microcerotermes beesoni* Snyder the proportion of immatures was highest in March-April, followed by October, and lowest in July and February. In *Nasutitermes dunensis* Chatterjee et Thakur, however, the maximum population of nymphs was recorded in July and the minimum in February. In addition, they found that, after the swarming of the alates, the population of the immature brood abruptly increased to a maximum in July and August. Singh & Singh (1981 a) recorded population peaks for adult soldiers, adult workers, nymphs and adult sexual forms of *Odontotermes obesus* (Rambur) during June-August, July-September, May-June and June-July, respectively. In *Odontotermes redemanni* (Wasmann), the population peak for adult sexual forms was recorded in June-July, for nymphs in April-June, for soldiers in August-September, and for workers in July and September. The total population of *Odontotermes obesus* (Rambur) was highest in August and lowest in April, whereas in *O. redemanni* (Wasmann), the maximum was recorded in September and the minimum in April.

Studies on the seasonal abundance of ants revealed that the peak number of *Dorilus orientalis* Westw. occurred in March (Patil *et al.*, 1981) and of *Dorilus labiatus* Schuck in March Apr.l and May (Banerjee & Choudhuri,1980). These results confirm the earlier report of Kundu *et al.* (1961). The latter workers also reported the abundance of a couple of soil inhabiting orthopteroids, such as "*Gryllus*"and *Gryllotalpa* in March and April, respectively. Patil *et al.* (1981) recorded the seasonal abundance of *Plebeiogryllus* (as *Platygryllus*) *gutteiventris* (Walker) and *Gryllotalpa* sp. (? *G. orientalis* Buoveister, as *G. africana* Beauvois) as being maximal in February. Reddy (1981b) recorded the peak abundance of *Brachytrupes portentosus* Lichtenstein during the first half of October and the lowest number in June.

The seasonal abundance of different species of Coleoptera, as reported by different investigators, has revealed that the maximum emergence of Coleoptera is in June and July (Desai & Patel,1965). For Scarabaeidae, Veeresh & Rajanna (1981) recorded the peak period of Scarabaeina in May, Aphodiina in January, Dynastina in July and Rutellina and Melolonthia in April and May. Patil *et al.* (1981) recorded peak catches of *Oryctes rhinoceros* L. and *Rhinyptia indica* Burm. in October, of *Anomala ruficapilla* Burm. in July, of *Anomala dorsalis* (F.) in June, and of *Maladera* sp. in September. Dutta & Gupta (1981) recorded the maximum number of Coleoptera in August followed by October. The family Scarabaeidae, dominant among other Coleoptera,was recorded maximally in August, when Staphylinidae were most numerous in February. Studies on Scarabaeidae larvae recorded maximum number of white-grubs in July and minimum in December (Vyas *et al.*, 1981).

Bhattacharya (1971) recorded the psocopteran, *Liposcellis transvallensis* Enderl as being most numerous during summer, and least so during the post-monsoon period. Mitra *et al.* (1977, 1981) reported that Collembola showed two distinct peaks, one in July (monsoon) and the other in October (pre-winter and autumn). *Lepidocyrtus* sp., *Sphaeridia* sp., *Isotomina* sp. and *Megalothoras minimus* Willem were most abundant during August to October, while *Isotomina thermophila* Axelson, *Folsomides parvulus* Stach and *Subisotoma fitchioides* (Denis) were commonest during June, July and November, respectively. In 1978, they recorded the maximum population of Collembola in July and the minimum in November for grassland, the maximum in September and the minimum in November in a banana plantation, the maximum in October and the minimum in November under *Ixora*, the maximum in October and the minimum in June beneath *Sansevieria* and the maximum in June and the minimum in August for a fallow drainage area, Eden Gardens (Calcutta). Hazra & Choudhuri (1981)recorded populations of five species of Collembola indicating two peaks, one being in July-August (monsoon) and the other, smaller, in December-January (winter); minimum numbers occurred in May. However, Choudhuri & Roy (1972) and Choudhuri & Banerjee (1975, 1977) observed only single peaks of collembolan abundance which occurred during July-August. Interestingly, Choudhuri & Roy (1971 b) reported a winter peak for *Lepidocyrtus* sp. at Burdwan but monsoon peaks in three other districts of West Bengal; this was most probably owing to vegetational and climatic differences. Similarly, Mukherjee & Roy (1981) recorded populations of Collembola at two different places as attaining peaks in different seasons; the maximum was recorded during monsoon at Burdwan, and during winter at Kurseong. Their population fluctuations for total Collembola were reflected by that of the dominant species, *Onychiurus himalayensis* at Kurseong, and *Lepidocyrtus suborientalis*. Similarly, *Isotoma* (*Desoria*) *trispinata* (MacGillivaray) the dominant species, reflected the fluctuations of the total Collembola fauna in *Pinus kesiya* plantations near Shillong (unpubl.). Choudhuri & Roy (1971 a) reported the occurrence of a peak population of *Cyphoderus assimilis* (Borner) in August-September, while *Cypoderus albinus* (Nicolet) reached a peak during September-October. Prabhoo (1976) reported a maximum abundance of Collembola during July-September and a minimum during summer months. Singh (1977) reported their peak abundance in July and their minimum number in November. Hazra (1978 a, b) however, recorded an irregular trend of fluctuation for Collembola. *Lepidocyrtus* sp., *Cyphoderus javanus*, and *Brachystomella* sp. were recorded as being most numerous in July and fewest in May, with a second peak in December-January. Choudhuri *et al.* (1978) also recorded similar findings.

Studies on the seasonal fluctuation of numbers of Acari according to Prabhoo (1976), indicated that all groups showed single peaks during the monsoon season. Mukharji & Singh (1970), however noted two peaks. Choudhuri & Banerjee (1975) reported single peak of abunddance of Acari in July-August with minimum number in April. Mitra *et al.* (1981) recorded maximum numbers of Acari from August to October and minimum in November. Choudhuri & Banerjee (1975), however, did not find

any definite winter or autumn peak. Choudhuri & Pande (1981) recorded Acari populations as being maximal in March (spring) and minimal in July (monsoon). Banerjee & Roy (1981) reported population peaks for Acari, particularly for *Scheloribrates albialatus*, *Archegoutes magna*, *Epilohmannia pallida* and *Hypoaspis bengalensis*, during the monsoon (July-August), with minimal in summer (Apil-May). Singh (1977) recorded maximum number of mites in August and minimum number in October-November. Darlong & Alfred (1982) reported Collembola and Acari to be most numerous in May, in a forest system at Upper Shillong, whereas Collembola alone were recorded in maximum number in jhum fallows in May, and Acari alone in November. At Barapani and Barnihat forest sites the peak abundance of Collembola was recorded in September. However, Acari were at a maximum in the former site in February and in the latter site in May. In the jhum fallows of Barnihat and Barapani, the Collembola and Acari were most abundant in September and least so in February. Singh & Mukharji (1971) recorded maximum populations of Collembola and Acari during August and November and minimum population in March.

Prabhoo (1976) reported the greater number of Cryptostigmata and Mesostigmata during July-September and the least in May. For Cryptostigmata (oribatid mites) alone, Sanyal (1981 a, b, 1982) and Sanyal & Bhaduri (1982) recorded two peaks of population, one in May-June (pre-monsoon) and the other in November (winter), with minimal numbers in December-January (winter). Nymphs of this group were recorded as being most abundant in May and November. Bhattacharya & Roychoudhuri (1979) who also observed two peaks, recorded them at different times, one being in September-October and the other in May-June. Ghatak & Roy (1981) also recorded population peaks in August (monsoon), when the jute crop was in the field, another peak being noted for March. The population was minimal in summer. Joy & Bhattacharya (1981 a). Bhattacharya & Roychoudhuri (1979) and Prabhoo (1976) reported that Cryptostigmata peaked in October (post-monsoon) and to a lower degree in May-June (pre-monsoon).

Prabhoo (1976) reported that Symphyla and Protura were most numerous during July-September. Singh (1977) recorded a maximum abundance of arthropods other than Collembola and mites during July and a minimum during November.

Investigations on the seasonal abundance of total arthropod populations showed their maximum abundance to be in August and their minimum in May-July (Singh & Mukharji, 1971). Bhattacharya (1971) recorded the maximum population of total arthropods during the post-monsoon period. Singh (1977) recorded the peak abundance of total arthropods in August and the minimum in November. Vatsauliya & Alfred (1980) recorded the populations of total arthropods only in different soil layers; there were maximal in July, June, March and April in the 0-10cm layer; in December, June, August and October in the the 10-20 cm layer; in May, June, August and April in the 20-30 cm layer; and in April, May and August, in the 30-40cm layer; their data were from 1,5, 10 and 20-years old jhum fallows, respectively. By contrast, Darlong & Alfred (1982) recorded the maximum populations of total arthropods

as being in May in different forest and jhum fallows at Upper Shillong, in September in jhum fallows at Barapani, and in March in the same two situations at Barnihat. In both forest and jhum fallows, the minimum numbers were recorded in December at Barnihat. However, in the lower (20-40 cm) layers, the maximum population was recorded in May at all the sites except Barnihat. Minima in jhum sites were recorded in September and February.

The vertical migration of soil inhabiting arthropods is a common phenomenon. Although they are usually more numerous in the upper soil layers (Prabhoo, 1981) they often move downwards. Ananthakrishnan (1979) following earlier authors, stated that microarthropods having different morphological features preferred different layers of soil. There is however, no rigid limitation to the distribution of such pedobionts. Singh & Singh (1975) recorded more Acari, Collembola and other arthropods in the 0-15 cm layer than in the 15-30 cm layer of the soil. Gupta & Mukherji (1976 b) recorded various species of *Japyx* down to a depth of 45-45.7 cm. Collembola, however, are generally more or less uniformly distributed in both cultivated and uncultivated soils, within the upper (0-22.8 cm) and lower (22.8-47.5cm) layers. Bhattacharya & Joy (1978) investigated the vertical distribution of total arthropods in the soils of different sites and found that they were considerably more numerous in the upper (0-5 cm) than in the lower (5-10 cm) layer. They found that these differences were more evident in undisturbed systems with good plant cover. Similar patterns of vertical distribution for total microarthropods have also been recorded by other authors (Trehan, 1945; Singh & Pillai, 1975; Darlong & Alfred, 1982), and for Collembola alone (Choudhuri & Roy, 1967, 1971 a, b, 1972; Hazra, 1976, 1978 a,b). Singh *et al.* (1979) have recorded maximum numbers of Collembola, Cryptostigmata, Prostigmata and Mesostigmata and "other arthropods" in the upper layers (0-5 cm) of an unpolluted soil system, but in a polluted system, the Cryptostigmata and "other arthropods" were recorded at maximum levels in deeper layers (15-20cm). It was believed that the pollutants dumped on the soil surface probably drove the arthropods to the deeper layers. Bhattacharya *et al.* (1981) reported that the Cryptostigmata in an *Acacia* forest soil profile preferred to remain in the upper (0-5 cm) layer of the soil, except for *Epilohmannia pallida indica* which were also equally distributed between 0-5 and 5-10 cm layers. Banerjee & Roy (1981) indicated the acarine population of the upper soil layer to be numerically greater as compared with the lower layers. However, in summer months, the populations in the lower layers were fairly dense, which may have been owing to temporary downward migration of some surface forms. Vatsauliya & Alfred (1980), surprisingly recorded greater numbers of arthropods, not only in 10-20 and 20-30 cm layers, but also in 30-40 cm layers, as compared with the uppermost layer in some months. This, however, seems scarcely credible, as the diameter of soil cavities normally decreases with increasing depth, thus limiting the penetration of many less minute soil microarthropods. Choudhuri & Pande (1981) recorded maximum numbers for all the groups of soil mites in the 0-8 cm soil layer as compared with the lower 8-15 cm layer both at Birch Hill and zoological garden sites, West Bengal. Many larger arth-

ropods, such as termites and crickets (Reddy, 1981 b) and white-grubs (Veeresh, 1977), of course, inhabit the deeper layers of the soil, but these are, excavaters or burrowers, which microarthropods are not.

Very little information is available on the horizontal distribution of soil arthropods. Bhattacharya *et al.* (1981) reported that species of Cryptostigmata (oribatid mites) showed a non-random aggregated horizontal distribution pattern. They noted the maximum degree of aggregation for *Archegozetes longisetosus* Aoki and *Scheloribates praeincisus* Berlese to be in grassland, followed, in the latter species, by banana plantation, paddy field and *Acacia* forest, in that order.

Similarly, information on the mathematical demography of soil arthropods is very scarce. Banerjee (1966, 1971, 1978), interpreted the data on population of mound building termite, *Odontotermes redemanni* (Wasmann), mathematically.

(e) Relationship with Environmental Factors

The influence of abiotic factors on the survival of poikilothermic invertebrates is considerable (Uvarov, 1931). The seasonal fluctuation, and vertical and horizontal distribution of soil arthropods are governed by various environmental factors (Choudhuri, 1963; Choudhuri & Roy, 1966; Hazra & Choudhuri, 1983; Reddy, 1983 b). A number of investigators have studied soil arthropod populations in relation to various environmental factors. In India, rather few attempts have been made to discover the correlations between various species and groups of arthropods and physico-chemical factors such as soil moisture, organic carbon, soil temperature, pH, salinity, electric conductivity, phosphate, nitrate and calcium carbonate contents. Nevertheless, there have been a number of investigations aimed at relating different groups of soil arthropods with soil moisture and organic carbon content.

(i) *Soil moisture and relative humidity* : Trehan (1945) first studied the population densities of soil arthropods in relation to soil moisture. The occurrence of the arthropods was found by various authors to be positively correlated with soil moisture (Mukharji & Singh, 1970; Bhattacharya, 1971; Bhattacharya & Joy, 1978; Vatsauliya & Alfred, 1980; Reddy, 1980 b). Increases and decreases in soil moisture content numerically increased or decreased in turn the soil arthropod populations. Singh & Singh (1975) recorded a greater number of Collembola in soil having a higher percentage of moisture. Prabhoo (1976) reported that Collembola are very sensitive to moisture fluctuations and were greatly affected by it. Positive correlations between increase in moisture content and in Collembola populations have also been recorded by several investigators (Singh, 1975; Choudhuri *et al.*, 1978; Hazra, 1976, 1978 a, b; Choudhuri & Roy, 1966, 1972; Mukherjee & Roy, 1981; Hazra & Choudhuri, 1981). Hazra (1978 a, b) related the moisture content to the abundance of different dominant species of Collembola, such as *Lepidocyrtus* (*Acrocyrtus*) *heterolepis*, *Cyphoderus javanus*, *Lepidocyrtus medius*, all of which attained their peaks in July, when the soil moisture content was maximal.

Similarly, positive and significant correlation have been found between the levels of populations of different groups of Acari and soil moisture content (Sanyal, 1981 a, 1982;

Dhar *et al.* ,1981; Ghatak & Roy,1981; Banerjee & Roy, 1981). Nevertheless, Choudhuri & Pande (1979,1981) found a negative correlation between the Acarine fauna and soil moisture content. Joy & Bhattacharya (1981 a) showed any relationship between soil moisture and populations of Cryptostigmata (oribatids) to be insignificant. According to them, all the dominant and subdominant species preferred comparatively dry soil conditions, moisture requirements being less than 10%, except for *Eporibatula* sp. and *Oppia* sp. which were found to be widely distributed in different moisture regimes. These authors collected maximum numbers of *Eporibatula* sp. from soils with moisture ranges exceeding 20%.

Gupta (1968) studied the effect of moisture on the ant, *Oecophylla smaragdina* (Fabricius). Termites of the genus *Microcerotermes* preferred the soil with a moisture content of 15-20% (Sen-Sarma, 1974). Bhattacharya (1971) related the soil moisture content with psocid populations, and reported that they were more abundant in soil with low moisture content. Viswanath *et al.* (1978) reported moisture as an important factor for the survival of the weevil, *Polytus mellerborgii* (Boheman).

Mitra *et al.* (1977, 1981) recorded the lowest numbers of Collembola at the end of November when the relative humidity of the soil surface was lowest, but the population attained its peak at the end of July, when the relative humidity was high, thus indicating a positive correlationship between the two. Hazra (1982) recorded the highest percentage of total arthropods and Collembola in sites with higher relative humidity. On the other hand, Mitra *et al.* (1981) reported that Acari reached their peak of abundance with lower humidity. Relative humidity affected the longevity of pseudergates of *Kalotermes flavicollis* (Fabricius) (Sen-Sarma, 1964) and the survival of workers and soldiers of *Odontotermes obesus* (Rambur) (Agarwal, 1979), workers of *Microcerotermes beesoni* Snyder (Sen-Sarma & Chatterjee, 1966) and other termites (Singh & Singh, 1981b). It effected the survival time not only of different species, but also of different castes of the same species (Sen-Sarma & Chatterjee, 1966).

(ii) *Organic carbon (or matter)* : Greater soil arthropod populations associated with soils rich in organic carbon were reported many years ago by Trehan (1945), and more recently by Choudhuri & Roy (1971 a,c,1972) and Singh & Pillai (1975). Prasad (1965) recorded maximum populations for a variety of soil mites in clay soil compared to loam. Choudhuri & Banerjee (1975) found a positive correlation between organic carbon and arthropod populations. As compared to the other sites Bhattacharya & Joy (1978) recorded maximum microarthropod populations in fallow grassland, the soil of which was rich in organic carbon. Populations were recorded, as being minimum in eroded laterite soil, in which organic carbon was very meager. Choudhuri *et al.* (1978) and Hazra (1978 a) found a positive and significant correlation between populations of Collembola and the abundance of organic carbon. Increased mite populations in soil with increased organic carbon have been reported by Banerjee (1974 a), Singh & Pillai (1975), Choudhuri & Pande (1979, 1981) and Joy & Bhattacharya (1981 a). Furthermore, many investigators have found significant positive correlations between the amount of organic carbon and the abundance of Acari, particularly for Cryptostigmata (oribatids) (Banerjee, 1974 a; Choudhuri &

Banerjee, 1975; Singh & Pillai, 1975; Joy & Bhattacharya,1981a; Choudhuri & Pande,1981; Dhar *et al*, 1981; Ghatak & Roy, 1981; Banerjee & Roy, 1981; Sanyal, 1981 a, 1982). Joy & Bhattacharya (1981 a) demonstrated correlations between presence of organic carbon and populations of different species of certain oribatids, *viz Scheloribates albielatus* and *Pilobatella berlesei* Bhattacharya & Banerjee. *Oppia nodosa* Hammer, however, was found in soils with a wider range of organic carbon content. Choudhuri & Pande (1981) found a positive correlation between organic carbon content and mite populations in the lower layers of the soil at Birch Hill, West Bengal. On the other hand, their correlations were negative in the upper layers of soil at their zoological gardens site. Mukharji & Singh (1970) stated that the organic matter of the soil varied between very narrow range. Hence, they could find scarcely any correlation between organic matter content and soil arthropod population density.

(iii) *Temperature* : Mukharji & Singh (1970) reported that, where there was a rise in temperature, there was a decrease in soil arthropods, which may have been due to their downward migration. When lower temperatures and high moisture contents also caused a decrease in the population, and that when both the temperature and moisture content were high,the population showed an abrupt increase. Banerjee & Roy (1981) reported a large acarine population at moderate temperatures during the monsoon. High surface temperatures, however, lead to a reduction in arthropod population. Mukherjee & Roy (1981) also reached similar conclusions. Choudhuri (1960, 1961) studied the influence of temperature on the development and sex ratio of Collembola, and many investigators have found a positive correlationship between temperature and the size of their natural populations (Mitra *et al.*, 1977; Choudhuri *et al.*, 1978) and mites (Sanyal, 1981 a; Choudhuri & Pande, 1981). On the other hand, soil temperature has been reported by some authors to be having a negative correlation in respect of the size of populations of Acari (Ghatak & Roy, 1981; Choudhuri & Pande, 1981) and Collembola (Hazra, 1982), indicating the populations to be at their peaks under low temperature regimes. Be that as it may, Vatsauliya & Alfred (1980) following earlier authors have stated that temperature is of lesser importance than other factors for soil dwelling animals. The effect of temperature on the survival of termites which are a special case, as they themselves regulate temperatures within their habitations, has been reported (Agarwal, 1979; Singh & Singh, 1981 b).

(iv) *pH, salinity and conductivity* : Mukharji & Singh (1970) could find scarcely any relationship between pH and the population of soil arthropods; but Choudhuri & Banerjee (1975), on contrast, found a positive correlation. Hazra (1982) recorded the highest numbers of arthropods in sites with a more or less neutral pH. Choudhuri & Roy (1967, 1971 a, 1972) and Choudhuri *et al.* (1978) could not establish any relationship between soil pH and the size of Collembola populations. Hazra *et al.* (1976) reported that Collembola were either negatively correlated with the pH or showed a weak positive correlation, indicating pH to have little or no influence. Joy & Bhattacharya (1981 a), however, found a statistically insignificant relationship between pH

and oribatid mite populations, indicating that pH may have a slight influence. All the common oribatid species, except *Eohypochthonius vilhenarum* (Balog), *Microzetes auxiliaris* Grandjean, and *Oppia* sp. preferred slighly acidic over an almost neutral pH. *Eohypochthonins vilhenarum* (Balog) and *Microzetes auxiliaris* Gradjean showed definite preferences for slightly acidic conditions; *Oppia* sp. preferred a more strongly acidic pH range. In some habitats, acarine populations were recorded as decreasing with decreased acidity (increased pH value) (Sanyal, 1981 b; Bhattacharya & Roychoudhuri, 1979; Choudhuri & Pande, 1981), but by constrast some investigators have found positive correlations between acarine popopulation and pH that indicated a rise in pH value (decreased acidity) increased the population (Ghatak & Roy, 1981; Choudhuri & Pande, 1981; Sanyal, 1981 b).

Sanyal (1981 b) reported a positive correlation between salinity and populations of oribatid mites, more of such mites being present during those months in which the salinity of the soil was higher, and fewer when it was lower. No significant relationship between electrical conductivity and the size of oribatid populations was found by Sanyal (1981 a).

(v) *Nitrate, available phosphate and calcium carbonate* : Positive correlations between soil nitrate and increase in numbers of Collembola have been reported by several authors (Choudhuri & Roy, 1971 a, c; Hazra, 1976; Choudhuri *et al.*, 1978). Choudhuri & Pande (1981) also found a similar positive correlation between nitrate content and acarine populations, in both upper and lower layers of the soil. On the other hand, they found a negative correlation between populations of Acari and nitrate content in some other plots, thus agreeing with the findings of Hazra (1976).

Available phosphate has been reported to have a negative correlation with the size of collembolan populations (Choudhuri *et al.*, 1978; Hazra & Choudhuri, 1981). Sanyal (1981 a, 1982), however, was unable to find a significant correlation between populations of oribatid mites and phosphate, which confirms the earlier findings of Choudhuri & Banerjee (1977). Such effects of insignificant relationships may suggest that the amount of available phosphate has little influence in oribatid faunal make up.

Choudhuri *et al.* (1978) attempted to relate calcium carbonate content to collembolan populations but could find no association between them.

Some investigators are of the opinion that, when two or more factors combine together, they exert a more significant influence on the populations of soil arthropods. Mitra *et al.* (1981) stated that changes in relative humidity of soil surface, combined with changes in soil temperature, played a significant role in limiting populations of Collembola. Raina *et al.* (1979) considered that the highest numbers of Acari probably occurred in response to high percentage of moisture content with the presence of abundant organic carbon. Choudhuri & Banerjee (1977) and Sanyal (1981 a) also reached similar conclusions. Mitra *et al.* (1981) stated that lower temperature and humidity were preferred by Acari, that of course, applies to tropical specifically Indian conditions. Reddy (1983 b) pointed out that not all but some of the environmental factors during a particular season become operation-

ally significant in increasing or decreasing the abundance of a particular species population. Acari which increased in number at lower temperature, rainfall and soil moisture conditions during winter (October-March) in *Pinus kesiya* plantations, for example, were recorded in minimal numbers during the monsoon (April to September), while Collembola and other edaphic arthropods were more abundant when the temperature and relative humidity were higher during the monsoon and least so during winter. Under any given set of abiotic environmental factors, some species of arthropods are favoured and become dominant, whereas others remain or become subordinate.

(f) Food and Feeding

Studies on the ecology of food and feeding of soil arthropods help in the understanding of the functioning of the soil and litter subsystem, the relationship between the different populations of soil arthropods, the nutrient cycling, and the energy flow with in the ecosystem (Usher *et al.*, 1982). Different groups of soil inhabiting arthropods exhibit a variety of trophic relations and are specialised to a variety of food materials. Investigations on the food and feeding of these arthropods are very scanty and scattered. The foraging activities even of termites, have been paid little attention (Banerjee, 1975; Rajagopal & Veeresh, 1981). Mukherji & Mitra (1949) reported that soldiers, and as well as mature and immature workers of *Odontotermes redemanni* (Wasmann) forage,though Rajagopal & Veeresh (1981) and Veeranna & Basalingappa (1981) have stated that only minor and major workers of *Odontotermes wallonensis* Wasmann are involved in foraging.

Root feeding larvae of Coleoptera has received the attention of several investigators (Bhadauria & Nigam, 1982). The larvae, soon after emerging from the eggs move in search of living roots. Veeresh (1977) reported that the first instar larvae of *Holotrichia serrata* Fabricius, feed on organic matter, and whilst so feeding, when they come in contact with living roots they attack these in preference to the organic matter. The instars cannot pupate without feeding on live roots. Among various crop roots, the larvae of this species preferred groundnut and french bean. Millipedes have been reported to feed on soil rich in organic matter in the absence of plant materials (Bano *et al.*, 1976; Bano & Krishnamoorty, 1981 a). They prefer soil having a high concentration of decomposing leaves, mango litter and soil mixed with cowdung. Soil containing *Eucalyptus* leaf litter, however, was unattractive to millipedes. It has also been noted by the same authors that soil and litter, while passing through millipedes' gut, are acted upon by various symbiotic fungi. The feeding activity of millipedes is influenced by various environmental conditions, the period of activity being dependent on humidity and water resources of the soil, as indicated for certain Europaean species by Banerjee (1967 a, b). The feeding activity was recorded (Bano *et al.*, 1976) as being maximal during the first two hours after sunrise.

Very little information is available on the food and feeding of other soil arthropods though Haq & Prabhoo (1976) have recorded oribatid mites feeding on decaying parts of higher plants as on microflora. Muraleedharan & Prabhoo (1978) studied the gut content of different species of Collembola and found that

these insects could be selective feeders, different species feeding on different materials. Reddy & Das (1983) have recently reported on the microfungal food preferences of various micro-arthropods particularly of Acari, and have recorded maximum number of Mesostigmatid mites, being attracted to different fungal baits; Collembola were also reported as occurring in maximum numbers in control baits, the agar of which grows colonies of a number of species of fungi under field conditions. Kurup & Prabhoo (1982) indicated that the food quality influenced the reproduction and longevity of the collembolan, *Cryptopygus thermophilus*. Reddy *et al.* (1978) recorded the oribated mites, *Galumna flabellifera* Hammer as being both fungivorous and saprophagous under field conditions; they isolated eight species of fungi from both its body surface and gut.

Many arthropods are predaceous upon others within the soil subsystem. Predation on Collembola by different kinds of arthropods, such as Mesostigmatid mites, ants and Centipedes (Reddy, 1980 b), and by pseudoscorpions (George & Prabhoo, 1981) have been reported. The pseudoscorpions showed a marked preference for unpigmented *Cyphoderus* sp., *Alloscopus* sp. and *Lepidocyrtus* sp. Verghese & Veeresh (1978) have reviewed the behaviour of ants, including predominantly predatory species. The workers of *Dorilus orientalis* Westw. were recorded as feeding on insect larvae and earthworms and on the termite *Microtermes mycophagus* (Desneus) (Sharma & Bhora, 1968). Jayaramaiah & Veeresh (1978) considered the soil inhabiting predatory insects and stated that various species of Carabidae were the predators of pest insects which has long been known.

(g) Energy and Nutrient Content

Energy flow within the ecosystem can be measured by knowing the energy content of its inhabitants. However, very little information is available on the energy content of these pedobionts (Singh & Yadav, 1973; Singh, 1979). Singh & Yadav (1973) measured the energy contents of insects occurring in grassland; and Singh (1979) recorded the energy content of the insects found in six different habitats, including soil and detritus inhabiting forms. Singh (1979) reported that the energy values for different insect species ranged from 5260 to 7219 cal/g dry wt. Among the soil and detritus inhabitants, the cricket *Gryllodes supplicans* (Walker) (as *Gryllus sigillatus* Walker) contained the maximum energy (6981.3 $\pm$ 711.1 cal/g dry wt.) followed by the beetle, *Syntelia indica* Fowl. (6432.7 $\pm$ 592.7 cal/g dry wt.) and the termite, *Macrotermes* sp. (6263.2 $\pm$ 513.1 cal/g dry wt.).

The biomass of the arthropods possess a large pool of nutrient elements. Singh (1979) analysed the mineral content of the detritivorus, *Syntelia indica* Fowl. and the omnivorous, *Gryllodes supplicans* (*sigillatus*) and found that the former species possessed more Ca and K, while Na was higher in the latter.

(h) Association with other Edaphic Organisms

The arthropods exhibit symbiosis, mutualism, commensalism, competition, parasitism, predation, antibiosis, antagonism (Patil *et al.*, 1978), and cannibalism (Arora & Gilotra, 1960). The associations between soil arthropods and micro-organisms are mainly trophic and pathogenic. Associations between edaphic aphids and microorganism, including mycorrhiza

(Reddy & Sharma, 1981; Reddy & Verma 1981; Reddy & Das, 1983), between *Beauveria brongniartii* and white-grubs (Ranganathaiah *et al.*, 1973), between *Bacillus popilliae* and white-grubs, *Holotrichia serrata* Fabricius (David & Alexander, 1975; Veenakumari & Veeresh, 1982) and different groups of micro-organisms, particularly fungi, and termites of the genus *Odontotermes* (Bose, 1923; Mukherji & Mitra, 1949; Bakshi, 1951; Batra & Batra 1966; Das *et al.*, 1962; Sen-Sarma, 1974; Singh *et al.*, 1978) have been reported. Singh (1977), Singh & Shukla (1977), and Reddy & Das (1983) have investigated the association between different groups of soil micro-arthropods and the mycoflora of soil for deciduous forest and pine plantation system, respectively. Choudhuri & Roy (1970) have reported the interaction between soil Collembola and other edaphic arthropods, and Singh *et al.* (1979) recorded an inverse correlation between Collembola and mesostigmatid mites which may be due to predation upon the former by the latter. Such observations have also been reported by Singh & Singh (1975) and Reddy (1980). Interestingly, Arora & Gilotra (1960) have reported cannibalism in *Odontotermes obesus* (Rambur). In contrast several investigators have reported, not cannibalism, but an association known as inquilinism between different species of termites (Assmuth, 1913, 1915; Sen-Sarma, 1962; Basalingappa, 1971). Such associations take place mostly between a major species and one or more minor species of highly fecund termites with large populations. A number of ants also have been recorded as being predaceous upon termites. Many termitophilous insects, such as specialised species of Staphylinidae (Coleoptera), Phoridae (Diptera) and Collembola are closely associated with termites which lick the physiogastric abdomen and exudatory appendages of these inquiliner insects which in turn, receive food and shelter from the termites (Sen-Sarma, 1974).

(i) Influence of Human Activities

It has been observed that the afforestation of treeless, stone-covered hillocks at various places led to a significant increase of soil arthropods. On the other hand, Prabhoo (1976) found a drastic reduction in their population with the conversion of forest into tea-gardens. Besides this, forest fires and controlled burning have been shown to have reduced the populations of various group of soil arthropods (Reddy, 1983a; Reddy & Tiwary, unpubl. data). Darlong & Alfred (1982) also reached similar conclusion, that the natural forest ecosystems, when cleared by slash and burning for cultivation considerably reduced the population of soil micro-arthropods. Reddy & Ao (unpubl.) have studied the effects of agriculture and building construction on the soil arthropods of a mixed deciduous forest ecosystem and have found considerable reduction in both the qualitative and quantitative composition of different groups of hemiedaphic and euedaphic arthropod fauna. Reddy (1981 b), however, recorded greater number of large burrowing crickets (*Brachytrupes*) in a roadside earth drainage system and in a farmyard as compared with undisturbed grassland.

There is hardly any information for India on the deleterious effects of agricultural operations on soil arthropods. Agricultural practices have disturbed the soil system and this has reduced the soil micro-arthropod

populations in various situations, such as in cotton and paddy fields (Trehan, 1945; Bhattacharya & Joy, 1978; Bhattacharya *et al.* 1980 b). The affect of pesticides and herbicides can cause irrepairable damage to the ecosystem as a whole by affecting its component parts. Sengupta (1981) has reported that field crickets are more susceptible than millipedes to the insecticides. The overall effect of these insecticides, however, particularly of organochlorines,have reduced the populations of carabid and staphylinid beetle populations and led to a change in the qualitative composition of the former. Some insecticides, such as Parathion, Phorate, Disulphoton and Carbaryl have reduced the beetle population, but DDT did not do so of Collembola and mites, even though it was applied in higher doses than normal. Some other insecticides, such as Cyclodiens, have nevertheless reduced micro-arthropod populations. Repeated applications of DDT, Aldrin, Dieldrin have reduced the millipede populations. Studies on the effect of different herbicides and insecticides on micro-arthropods (Bhattacharya & Joy, 1980 a, b, c; Joy & Bhattacharya, 1981 b; Kumar & Agarwal, 1983) have indicated that herbicides have either increased or decreased the population densities of Acari and Collembola. A number of insecticides have controlled the populations of white-grubs (Veeresh, 1977) and termites (Roonwal, 1979). The stability of certain insecticides may result in unexpected effects on soil arthropods a long time after their application (Kühnelt, 1963). Industrial wastes and other pollutants discharged from different sources have been reported to decrease the population of soil arthropods remarkably (Singh & Tripathi, 1978; Singh *et al.*, 1979; Bhattacharya *et al.*, 1980 a).

LITTER ARTHROPODA

Plant litter includes various plant materials, ranging from soft and fragile leaf tissues to tough and undecomposed wood (Edwards, 1974). The micro- and macro-arthropods inhabiting the plant litter, such as Collembola, Acari, Diplura, Thysanoptera, Protura, Symphyla, Tardigrada (Harding & Stuttard, 1974) and Isopoda, Diplopoda, Isoptera, dipteran larvae, coleopteran larvae and adults (Edwards, 1974) may be designated as litter arthropods.

(a) Methods of Analysis

The litter inhabiting arthropods have been studied by sampling litter manually from a unit area and processing the samples through Berlese-Tullgren-type funnels (Singh & Singh, 1975; Singh, 1977; Raina *et al.*, 1979). This method however, leads to spillage and hence the loss of a considerable number of the arthropods. Thus, the arthropods extracted may not be true representative of the fauna, either qualitatively or quantitatively. Instead Gupta & Singh (1977), Reddy & Alfred (1978) and Reddy (1981a) have used the litter-bag method and have studied the structure and function of litter inhabiting arthropod communities more directly. Although, this method has some disadvantages, it is the most acceptable and suitable method.

Litter arthropods may also be sampled with the help of a split-core sampler (O' Connor,1957), taking cores of litter and soil together, and later separating the litter layer from the underlying soil of the core by means

of a thin knife blade and then processing the litter separately through dry-funnel extractors. This gives qualitative and quantitative composition of the litter inhabiting arthropods, although those originally inhabiting the litter layer may move downwards as a result of pressure exerted by the core samplers. Nevertheless, this method of sampling for litter arthropods may be more accurate than of Singh & Singh (1975).

(b) Population Abundance

Singh & Singh (1975) recorded that among the mites, the Cryptostigmata being dominant were 42.5% of total arthropods. They were followed in number by Mesostigmata, Prostigmata and Astigmata combined constituted the smallest number. Singh (1977) recorded maximum numbers for Acari, which constituted 56.09%, whereas Collembola were minimal among the different groups of litter arthropods. Reddy & Alfred (1978) compared the relative abundance of microarthropods for five pine plantations, and found that Acari were dominant in all sites except one, where Collembola were more numerous, Acari being at second place. Arthropods other than Collembola and Acari, were least abundant. Reddy (1981 a) found that among the micro-arthropods associated with decomposing pine needle litter, Collembola were dominant, followed by Acari. Raina *et al.* (1979) recorded maximum density of mesofauna in the forest litter when compared with the ungrazed and grazed pasture areas where the population of Acari was the greatest followed by Collembola. Hazra (1982), although processed litter of Silent Valley for the extraction of arthropods, but could not comment on abundance of litter arthropods separately.

Banerjee (1967 a) recorded the seasonal changes in the distribution of the Europaean diplopod, *Allajulus* (*Cylindrojulus*) *punctatus* (Leach) in decaying logs. Bano & Krishnamoorty (1978) reported that the Indian millipede, *Jonespeltis splendidus* (Verhoeff) was more frequent in mixed deciduous leaf litter as compared to coffee plantation. Singh (1977) recorded maximum numbers of litter inhabiting Acari which reflected the abundance of total arthropods in August, and of Collembola and other arthropods in July and minimum in November. In pine plantations, Reddy & Alfred (1978) have recorded maximum number of Collembola and Acari in October in all except one in which the maximum was in July, and another where Acari were most abundant in June. Arthropods of other miscellaneous groups were too few to exhibit any seasonal pattern of abundance. Reddy (1981 a) recorded a maximum number for total litter inhabiting arthropods in October and a minimum in February, the Collembola being the most dominant, showed a pattern of seasonal fluctuation more or less similar to that of total arthropods, but with a peak in June. Collembola outnumbered the Acari throughout the year, except from November to February when the latter were dominant.

Maximum numbers of arthropod groups were recorded in northeast Indian mixed deciduous forests, followed by pine forests (Reddy, Reddy & Tiwary, unpubl). Raina *et al* (1979) have recorded maximum numbers per m^2 for Collembola, Acari and other arthropod in a forest ecosystem. The minimum number of

Collembola, Acari and other arthropods per m^2 were recorded in sal forests near Varanasi (Singh, 1977).

(c) Relationship with Environmental Factors

Reddy & Alfred (1978) attempted to correlate the abundance of different groups of arthropods encountered in litter bags, with litter moisture and temperature inside the bags, but they could establish no significant correlation. Nevertheless, the author (unpubl.) found that Collembola of the family Entomobryidae, and mites of the orders Prostigmata, Mesostigmata and Cryptostigmata inhabiting litter bags, showed a negative but significant correlation with litter temperature in 3.0 mm^2 mesh bags, both Mesostigmata and Entomobryidae in 1.0 mm^2 mesh bags, but Mesostigmata only in 0.3 mm^2 mesh bags. Total Collembola, Mesostigmata, and arthropods all showed a positive and statistically significant correlation with moisture in 3.0 mm^2 mesh bags; Isotomidae, Entomobryidae, total Collembola and total Acari in 1.0 mm^2 mesh bags; and Isotomidae, total Collembola and total arthropods in 0.3 mm^2 mesh bags. These findings, indicate therefore, that litter moisture and temperature have a favourable impact on the abundance of different groups of litter inhabiting arthropods.

(d) Food and Feeding

As with other parameters, very little information is available on the food and feeding of litter inhabiting arthropods also. Bano & Krishnamoorty (1981 b) reared the millipiede, *Jonespeltis splendidus* (Verhoeff) on leaf litter of mango, cassia, coffee and mixed deciduous trees, and found that the myriapods consume any type of soft and decomposing litre, preferring mango leaf litter. This millipede seemed largely in the litter of coffee plantations also. The author (unpubl.) has found small, round holes in pine needles (packed in nylon litter-bags) similar to those produced by the feeding activites of various oribatid mites. Gupta *et al.* (1981) reported that the termites, *Odontotermes gurdaspurensis* Holmgren et Holmgren preferred the shoot and root materials of *Chenopodium album*, which was consumed very rapidly, to that of *Desmostachya bipinnata*.

(e) Energy Relationships

Again there is little information on the energy relationships of arthropods inhabiting the plant litter. This is largely due to the complications and inaccuracies of using gravimetrical methods and oven dry weight estimates for the determination of the small amounts of litter consumed and egested by the animals. Nevertheless, attempts should be made at least for the more abundant species to determine the energy relationships of soil and litter arthropods in such matters as ingestion, accumulation and respiration; and this should be in respect to both adults and juveniles. Information on such relationships would greatly assist in the holistic understanding of ecosystem energetics (Harding & Stuttard, 1974).

EDAPHIC ARTHROPODA OF AGRO-ECOSYSTEMS

Studies on soil and litter inhabiting arthropods of different agro-ecosystems have virtually been confined to those species which directly affect the yields of the crop plants. In India, the realization that the edaphic arthropods of agro-ecosystems (other than those which infest the crops themselves) play a significant

role in the decomposer subsystem and in soil fertility is a recent one. In India, white grubs and termites, which directly affect various crop plants, their damage running into millions of rupees per year, have received much more attention (Veeresh, 1977; Pal, 1977; Chhotani, 1980; Roonwal, 1979, 1981). Investigations on other edaphic arthropods associated with different crops systems are few.

(a) Wheat

The infestation of wheat crop by cutworms, its seasonality and its control has been recorded by Vaishampayan (1981) and by Vaishampayan & Veda (1981). Verma *et al.* (1981) studied the effect of crop rotation on the damage caused to wheat by *Microtermes obesi* Holmgren and found maximum damage in crops sown after guar,(*Cyamopsis tetragonoloba*), and minimum after bajra,(*Pennisetum typhoides*). They could not find any difference in the termite damage when the crop was followed either by jowar, *Sorghum vulgare*, or mung, *Phaseolus aureus*. Bhattacharya & Joy (1980 a) and Joy & Bhattacharya (1981 b) performed a comparative assessment of some herbicides on the micro-arthropods of wheat fields.

(b) Other Cereals

The relative abundance of micro-arthropods in soil animals communities in lowland paddy fields (Bhattacharya & Joy, 1978), particularly the Cryptostigmata (Bhattacharya *et al.*, 1981) and the effect of some herbicides (Bhattacharya & Joy, 1980 b; Joy & Bhattacharya, 1981 b) and agro-technical measures (Bhattacharya *et al.*, 1980 b) have been investigated. Pai & Prabhoo (1980, 1981) studied the micro-arthropods inhabiting the paddy tillers during the post-harvest period and compared the fauna with the micro-arthropods of the adjoining uncultivated fields. Reddy & Ao (unpubl.) compared the qualitative and quantitative composition of both hemiedaphic and euedaphic arthropods, and their seasonal abundance for upland paddy and maize systems. Brar & Sandhu (1982) reported the ecobiology of a white grub, *Holotrichia* sp., in maize and sorghum pearl millet, and other crop systems.

(c) Pulses

Roonwal (1981) reported various termites attacking pulse crops. Termites have been recorded as damaging chickpea (*Cicer arietinum*), lentil (*Lens culinaris*), black gram (*Vigna mungo*), and green gram (*Vigna radiata*). These crops suffered comparatively greater damage by termites in sandy than in heavy soils (Chhabra, 1981). Vaishampayan (1981) and Vaishampayan & Veda (1981) studied the seasonal abundance of *Agrotis ipsilon* (Hufnagel) and its chemical control on different crops, including grams. The present author (unpubl. data) has conducted a preliminary study during winter on the micro-arthropods inhabiting a thick layer of leaf litter beneath a crop of *Cajanus* sp. Far less arthropods, and mostly xerophilic forms were recorded, probably because of the dry soil conditions.

(d) Sugarcane

The soil inhabiting arthropods, including white grub, in sugarcane fields have been investigated both qualitatively and quantitatively (Singh & Mukharji, 1971, 1973; Avasthy, 1967; David, 1978). David & Ananthanarayana (1974) reported that

the activity of beetles in the soil depended on some showers during March-April. Vyas *et al.* (1981) recorded the seasonal abundance of white grubs in sugarcane fields, populations being maximum in July 1978. Veeresh *et al.* (1978) and Sukhija *et al.* (1981) reported the efficiency of certain soil insecticides against the root grub, *Holotrichia serrata* Fabricius attacking various crops, including sugarcane. Roonwal (1981) reported that the attack of termites occurred both in pre- and post-monsoon periods when the cane is in active growth stages. Reddy & Tiwary (unpubl.) studied both the hemiedaphic and euedaphic arthropods of sugarcane fields and compared their qualitative and quantitative composition, and their seasonal abundance, with those of an adjacent bamboo forest.

(e) Cotton

Trehan (1945) first conducted investigation on the micro-arthropods fauna of cotton fields. Veeresh (1977) reported the ecology of white grubs under various crops, including cotton. Vaishampayan (1981) studied the seasonality of *Agrotis ipsilon* Hufnagel in cotton fields.

(f) Groundnut

Many investigators have reported on the ecology of root grubs, particularly *Holotrichia* sp. and on their damage to groundnut (Yadava *et al.*, 1977; Brar & Sandhu, 1980, 1981; Bakhetia, 1982). Brar & Sandhu (1981) studied the effect of dates of sowing on the damage by *Holotrichia consanguinea* Blanchard.

(g) Other Crops

Ghatak & Roy (1981) studied the seasonal abundance of five species of Acari of potato fields in relation to various environmental factors. The seasonal abundance of *Agrotis ipsilon* Hufnagel in potato fields has been studied by Vaishampayan (1981). The seasonal abundance and the qualitative and quantitative composition of different soil arthropods in rose gardens have also been investigated (Singh & Mukharji, 1971, 1973).

The ecology of the Acari in banana plantations was investigated by Singh & Pillai (1975, 1981) and Joy & Bhattacharya (1981 a). Mitra *et al.* (1977, 1978) have done the same for Collembola. Singh & Pillai (1931) also studied the abundance, composition and biocoenology of micro-arthropods in citrus orchards. The faunal composition and ecology of various groups of soil arthropods inhabiting tea gardens (Prabhoo, 1976; Reddy, 1981 c), and the efficacy of various insecticides in controlling the root grub, *Holotrichia serrata* Fabricius under various crop conditions including those in coffee plantations (Veeresh, 1977) have been studied. Ghatak & Roy (1981) recorded the seasonal abundance of different species of Acari in Jute fields, and Singh & Pillai (1981) of micro-arthropods of fodder crop fields.

ROLE OF SOIL AND LITTER ARTHROPODS

(a) Litter Decomposition, Humification and Soil Fertility

The decomposition of plant litter is the process by which the dead and shed plant parts lying on the soil surface are broken down into larger fragments, then into smaller particles and eventually into molecules. Soil and litter inhabiting arthropods play a significant role

in the breakdown of the plant litter. They physically disintegrate the plant tissue and increase the surface area for microbial activity, and they transform the plant residue into humic materials. They also help in the formation of complex aggregates between organic matter and the mineral fractions of the soil. In India, very little work has been done on such aspects of plant litter decomposition process (Singh & Gupta, 1977; Gupta & Singh, 1977; Reddy, 1979). Gupta & Singh (1977) attributed the greater weight loss from coarse mesh bags, as compared to the fine mesh bags, to the feeding activities of termites and other mesofauna. Reddy & Alfred (1978) related the abundance of litter arthropods to the weight loss of the litter. Reddy (1981 a) reported that the weight loss from pine needle litter decreased steadily with the passage of time. The total monthly abundance of micro-arthropods seemed to have a significant influence on the weight loss of needle litter. Gupta *et al.* (1981) investigated the role of the termite, *Odontotermes gurdaspurensis* Holmgren et Holmgren in plant decomposition in a tropical grassland. Bano & Krishnamoorty (1981 a) reported the relative rates of litter decomposition by *Jonespeltis splendidus* (Verhoeff) which ingests decaying organic matter along with soil, and deposits organic residues of humus in the form of dark coloured, flat, biparticle crumbs. These were accompanied by significant increases in oxidisable carbon, total carbon and C/N ratio. Moreover, these authors found that the ratios of humic to fulvic acids were comparatively lower in the excrement than in the soil and litter, indicating humification of soil by these millipedes. Banerjee (1972) associated micro-arthropods with humus formation. Other arthropods, such as ants and termites (Sen, 1944; Shrikhande & Pathak, 1948, 1951; Gokhale *et al.*, 1958; Pathak & Lehri, 1959; Banerjee & Mohan, 1976; Basalingappa *et al.*, 1978; Agarwal, 1978 a; Rajagopal *et al.*, 1982; Samra *et al.*, 1979; Gupta *et al.*, 1981) and millipedes (Bano & Krishnamoorty, 1977, 1978, 1981 a) have been shown to increase the nutrient status of the soil as their excreta contained higher amounts of various nutrients as compared with the underlying soils. Ant hills contained higher percentages of N, C, and organic carbon when compared with the termite soils (Shrikhande & Pathak, 1948, 1951). Sen (1944) reported that the nutrient composition of termite soils differs according to the food of the insects. These activities of soil inhabiting arthropods thus modify and/or magnify the nutrient status of the parent soils. Termites bring up the subsoil in a manner similar to certain earthworms. The soil brought up and deposited in the form of mounds, aerial nests on tree trunks, earthen sheets overlying dead wood and earthen galleries of termites ultimately become dispersed over wide areas and this, in turn, effects the physico-chemical nature of the soil (Chhotani, 1981). Joseph (1978) has observed that the surfaces of large mound of *Macrotermes* sp. are utilized for the cultivation of various crops which grew better in such situations; they had an intensified greenness and gave better yields indicating the higher fertility of the mounts, as compared with their surroundings. On the other hand, some species of humivorous termites deplete the available organic matter in the soil (Sen-Sarma, 1974, 1981).

Many other insects, such as crickets or wasps excavate in the soils (Reddy, 1981 b), by

which they bring soil from the lower layers to the surface, thus helping to mix the soil of different layers. Crickets can excavate as much as about 115 tonnes of soil per hectere per year. Investigations analysing the excreta of arthropods other than termites are very few. Bano & Krishnamoorty (1977, 1978) analysed the excrements of *Jonespeltis splendidus* (Verhoeff) for changes in the ratios of total Ca, Na, K, and pH, and were of view that defecation by millipedes humified loam and black clay loam soils, changing considerably their physico-chemical composition. The present author (unpubl.) analysed the soil excavated by a large burrowing cricket, *Brachytrupes portentosus* (Liechtenstein), but found hardly any increase in nutrient status.

(b) Role in Fungal spore Dissemination

The arthropods associated with mycorrhiza may help in their distribution and dispersal (Reddy & Sharma, 1981). Honeydew, secreted by aphids, which may reach the rhizosphere can support different types of microorganisms and so increase the rate of nitrogen fixation, as suggested by Owen & Wiegert (1976). According to Reddy *et al.* (1978), edaphic arthropods have also been reported to distribute and disseminate the spores of fungi. These authors recorded fungi belonging to three different species on the body surface of *Galumna flabellifera* Hammer which may indicate the importance of mites as fungal spore carriers. Reddy & Das (1983) also found fungal colonies on the simple agar media used as control in the experiment designed to attract microarthropods; this most probably, was a result of inoculation by edaphic arthropods visiting the media.

(c) Soil Aeration and Drainage

Investigations designed particularly in order to investigate the role of soil and litter arthropods in soil aeration and drainage and other physical properties of the soil in India are practically nil. Several investigators have, of course, reported on the vertical and horizontal movements of different arthropods within the soil, by which not only new cavities are created, but existing pore spaces become enlarged, and this assists in soil aeration and drainage. Some of the larger insects such as crickets actively excavate soil (Reddy, 1981 b), by which are created burrows that not only hold considerable amount of air but that also help in the infiltration of rain water. Reddy (*op. cit.*) reported that the average length of the excavations dug by *Brachytrupes portentosus* (Liechtenstein) was 40.03 ± 3.86 cm and its diameter 2.26 ± 0.14 cm. Many other insects, including orthopteroids, ants and wasps, also excavate the soil, creating small holes which, in turn, enhance soil aeration and drainage.

CONCLUSIONS

In India there is no area in respect of the ecology of edaphic arthropods where sufficient work has been done, and one might say that the same is true everywhere though some regions have been better investigated. There have, however, been many studies on the quantitative analysis of populations and communities of various arthropods which will help in understanding their population and community dynamics. Attempts to analyse other parameters such as food and feeding habits and the association of arthropods with other organisms, etc. are few. Yet studies on these parameters may provide information on various

aspects of the socio-ecology of the soil. The analysis of populations in relation to the environment would also help in understanding the key factors that influence population increases and decreases. As pointed out by Usher *et al.* (1982), studies made on groups of organisms relating only supraspecific taxa, leave much to be desired, for they cannot explain the population dynamics of individual species, and this shortcoming may be serious. Therefore, investigations should be made first at the species level, then at the population level within the community and only later on the organisation and dynamics of communities. A lacuna, lies in the lack of sound taxonomic groundwork enabling field workers to identify species.

The majority of Indian studies on the soil fauna have been made on the structure of different soil and litter inhabiting arthropods communities. Information on the functioning of the arthropod populations in the decomposer subsystem is very scanty, although the animals are known to perform a number of important functions (Hole, 1981). Emphasis should therefore be placed on research dealing with such functions under natural and simulated conditions. To understand the structure and function of these arthropods, integrated research should be undertaken by which researchers specialized in different subjects such as soil science, soil microbiology and general biology can work together on the soil litter subsystem of a particular ecosystem. In so doing, the relationships between different groups of soil fauna and the aboveground vegetation, the soil microorganisms and various abiotic environmental factors would be investigated in detail and interpreted properly.

Data on the ecology of soil and litter arthropods should, of course, be analysed statistically. The analysis of coefficients of correlation between arthropod population abundance and environmental factors should be treated with caution, as often the significant correlationships on paper fail to indicate or explain such phenomena as occur in nature. Moreover, statistically significant correlations may fail to show any cause and effect for the relationships indicated (Usher *et al.*, 1982).

Bearing in mind the enormous importance of various arthropods and members of other groups of the soil and litter fauna and microflora,on the one hand, and the insufficient knowledge of most aspects of pedobiocoenology on the other, it is exhorted that a separate research institute dealing specifically with soil biology and ecology and financed by the Government of India be opened in the country in order to encourage detailed research on the numerous aspects of pedobiology.

Acknowledgements : I am thankful to a number of researchers who responded to my request by sending their valuable reprints on the subject; to my wife for her assistance while preparing the manuscript; to my research fellows, Miss. M. Alemla Ao and Mr. S. P. Tiwary, who provided some of their unpublished information, and finally to Prof. Dr. D.K. McE Kevan (Canada) for reviewing the manuscript and improving it.

REFERENCES

ADIS, J. 1979. Problems of interpreting arthropod sampling with pitfall traps. *Zool. Anz.*, Jena, 202: 177-184.

AGARWAL, V.B. 1978 a. Some characteristics of Termitaria soil of *Odontotermes micro-*

dentatus Roonwal and Sen-Sarma, in relation to their surroundings. *Soil Biology and Ecology in India.* (eds.) C.A. Edwards & G.K. Veeresh, U.A.S. Tech. Series. 22: 199-202.

AGARWAL, V.B. 1978 b. Seasonal fluctuation of proportions of different castes as found in the fungus combs of *Odontotermes obesus* (Rambur) and *O. microdentatus* Roonwal and Sen-Sarma. *Soil Biology and Ecology in India. Ibid.* pp. 192-196.

AGARWAL, V.B. 1979. The effect of variation in temperature and relative humidity on the survival of workers and soldiers in *Odontotermes obesus* (Isoptera, Termitidae). *Acta entomol. Bohemosl.* 76: 158-161.

ANANTHAKRISHNAN, T.N. 1979. Microarthropods and soil systems. *J. Bombay nat. Hist. Soc.* 75: 625-631.

ANDERSON, J. M. and HEALEY, I. N. 1970. Improvements in the gelatin embedding technique for woodland soil and litter samples. *Pedobiologia* 8: 108-120.

ARORA, G L. and GILOTRA, S K. 1960. The biology of *Odontotermes obesus* (Rambur) (Isoptera) *Res. Bull. Punjab Univ.*, Chandigarh (N.S.) 10: 247-255.

ASSMUTH, J. 1913. Wood-destroying white-ants of Bombay presidency. *J. Bombay nat. Hist. Soc.* 22: 272-384.

ASSMUTH, J. 1915. Indian wood-destroying white-ant (second contribution). *Ibid.* 23: 690-694.

AVASTHY, P.N. 1967. The problem of white-grubs in India. *Proc. ISSCT 12th Cong.* 17: 1321-1333.

BAKHETIA, D.R.C. 1982. Studies on the white grub, *Holotrichia consanguinea* Blanchard in the Punjab. Control and yield losses due to white grub and collar rot of groundnut. *J. Soil. biol. Ecol.* 2: 40-46.

BAKSHI, S.K.1951. Fungi in the nest of *Odontotermes obesus*. *Indian Phytopathol.* 4: 1-4.

BANERJEE, B. 1966. A statistical study of the population of the tropical mound building termite *Odontotermes redemanni* (Wasmann). *Insect Sociaux* 13: 29-38.

BANERJEE, B. 1967 a. Seasonal changes in the distribution of the millipede *Cylindroculus punctatus* (Leach.) in decaying log and soil. *J. Anim. Ecol.* 36: 171-177.

BANERJEE, B. 1967 b. Diurnal and seasonal variations in the activity of the millipedes *Cylindroculus punctatus* (Leach.), *Tachypodoiulus niger* (Leach.) and *Polydesmus angustus* Latzel. *Oikos* 18: 141-144.

BANERJEE, B. 1971. Dynamics of termite populations. Some theoretical considerations. *Insect Sociaux* 18: 21-28.

BANERJEE, B. 1975. Growth of mounds and foraging territories in *Odontotermes redemanni* (Wasmann). *Ibid.* 22: 207-212.

BANERJEE, B. 1978. Mathematical demography of *Odontotermes redemanni* (Wasmann). *Proc. Indian nat. Sci. Acad.* 44, B: 91-98.

BANERJEE, J. and ROY, S. 1981. Acarina community of a forest ecosystem in Burdwan. *Contributions to Acarology in India.* (ed.) G. P. Channa Basavanna, A.S I., Bangalore, pp. 28-32.

BANERJEE, S. 1972. Microarthropods and humus formation. *J. Indian Soc. Soil Sci.* 20: 403-405.

BANERJEE, S. 1974a. Oribatid mites and organic carbon content of soil. *Acta Arachnol.* 26: 47-50.

BANERJEE, S. 1974 b. Qualitative composition and seasonal fluctuation of Oribatei (Acarina) in Burdwan soil, West Bengal (India). *Ibid.* 25: 68-72.

BANERJEE, S.P. and MOHAN, S.C. 1976. Some characteristics of Termitaria soils in relation to their surroundings in New Forest Estate, Dehra Dun. *Indian For.* 102: 257-263.

BANERJEE, T.C. and CHOUDHURI, D.K. 1980. Studies on the seasonal variation of swarming of the males of *Dorylus labiatus* (Hymenoptera : Formicidae) in relation to some environmental factors. *Rev. Ecol. Biol. Sol.* 17: 217-227.

BANERJEE, T.C., NAYEK, T. K. and MONDAN, A.S. 1981. The influence of moonlight on the catches of *Clivina helferi Putzeys* (Coleoptera : Carabidae). *Ibid.* 18: 403-412.

BANO, K. and KRISHNAMOORTY, R. V. 1977. Changes in the composition of soil due to defaecation by the millipede, *Jonespeltis splendidus* (Verhoeff). *Mysore J. agric. Sci.* 11: 561-566.

BANO, K. and KRISHNAMOORTY, R.V. 1978. The role of the millipede, *Jonespeltis splendidus* (Verhoeff) in soil humification. *Soil Biology and Ecology in India.* (eds.) C.A. Edwards & G.K. Veeresh, U.A.S. Tech. Series. 22: 106-110.

BANO, K. and KRISHNAMOORTY, R V. 1981 a. Relative rates of litter decomposition and humification of various soils by the millipede, *Jonespeltis splendidus. Progress in Soil Biology and Ecology in India.* (ed.) G.K. Veeresh, U.A.S. Tech. Series. 37: 87-92.

BANO, K. and KRISHNAMOORTY, R.V. 1981 b. Consummatory responses of the millipede, *Jonespeltis splendidus* (Verhoeff) in relation to soil organic matter. *Proc. Indian Acad. Sci.* (*Anim. Sci.*) 90: 631-640.

BANO, K., BAGYARAJ, D. J. and KRISHNAMOORTY, R.V. 1976. Feeding activity of the millipede, *Jonespeltis splendidus* (Verhoeff) and soil humification. *Proc. Indian Acad. Sci.* 83: 1-11.

BARNES, H.F. 1941. Sampling for leather jackets with Orthodichlorobenzene emulsion. *Ann. Appl. Biol.* 21: 23-28.

BASALINGAPPA, S. 1971. Association of *Speculitermes cyclops, Dieuspiditermes* (*Capritermes*) *incola* and an undetermined species of *Microtermes* with *Odontotermes assmuthi. The Indian Zool.* 2: 67-72.

BASALINGAPPA, S., MAHALE, V.B., KULKARNI, V.H. and BIRADAR, N.S. 1978. Chemical components of the mound soil and that of royal chamber of the termite, *Odontotermes assmuthi* Holmgren (Termitidae: Isoptera). *Soil Biology and Ecology in India.* (eds.) C. A. Edwards & G. K. Veeresh, U.A.S. Tech. Series. 22: 203-206.

BATRA, L.E. and BATRA, S.W.T. 1966. Fungus growing termites of tropical India and associated fungi. *J. Kansas Entomol. Soc.* 39: 725-738.

BELLINGER, P.F. 1954. Studies of soil fauna with special reference to Collembola. *Comm. Agric. Expt. Stat. Bull.* 583: 1-67.

BHADAURIA, A.S. and NIGAM, P.M. 1982. Food preference of *Holotrichia consanguinea* Blanchard (Coleoptera : Scarabidae). *Entomon* 7: 331-332.

BHATTACHARYA, T. 1971. Some ecological studies on the *Liposcellis transvallensis* Enderl. *Visva-Bharati Annals, Science*, 14-part 2: 30-34.

BHATTACHARYA, T. and JOY, S. 1978. A study of soil microarthropod community of four contrasting soils in Sriniketan, West Bengal. *J. Res. Visva-Bharati* 2: 17-28.

BHATTACHARYA, T. and JOY, V. C. 1980 a. Impact of Bladex-C (Amine 2, 4-D) upon density of soil micro-arthropods of a wheat field. *Proc. Environ. Biol. Symp.* Trivandrum, pp. 206-211.

BHATTACHARYA, T. and JOY, V. C. 1980 b. Changes in abundance of soil inhabiting Acari of a paddy field in response to application of two herbicides. In: *Pesticide Residue in the Environment in India.* (eds.) C.A. Edwards, G.K. Veeresh & H.R. Krueger, U.A.S. Tech. Series, 32: 502-513.

BHATTACHARYA, T. and JOY, V. C. 1980 c. Effects of two herbicides on soil inhabiting Cryptostigmatid mites. In: *Soil Biology as related to Land use Practices.* (ed.) D.L. Dindal, U.S., E.P.A., Washington, pp. 109-118.

BHATTACHARYA, T. and ROYCHOUDHURI, D.N. 1979. Monthly variation in the density of soil microarthropods in relation to some climatic and edaphic factors. *Entomon* 4: 313-318.

BHATTACHARYA, T., BHATTACHARYA, J. and BANERJEE, R. 1980 a. A preliminary survey of the effect of some emission from a husking mill on the soil microarthropods. *News Letter Soil Biol. & Ecol.* 1: 15-17.

BHATTACHARYA, T., JOY, V.C. and JOY, S. 1980 b. Soil inhabiting Cryptostigmata (Acari) of the rice field ecosystem in relation to agrotechnical measures. In : *Tropical Ecology and Development*, (ed.) J.I. Furtado, *Proc. V. Intern. Symp. Trop. Ecol.* Kuala Lampur, Malaysia, pp. 981-988.

BHATTACHARYA, T., JOY, S. and JOY, V.C. 1981. Community structure of soil Cryptostigmata under different vegetational conditions at Santiniketan. *J. Soil Biol. Ecol.* 1: 27-42.

BOSE, S.R. 1923. The fungi cultivated by termites of Barkuda island. *Res. Indian Mus.* 25: 253-258.

BRAR, K.S. and SANDHU, G S. 1980. Biology of *Holotrichia consanguinea* Blanchard infesting groundnut in Punjab. *Indian J. Entomol.* 42: 426-433.

BRAR, K.S. and SANDHU, G.S. 1981. Notes on the effect of dates of sowing on the damage by *Holotrichia consanguinea* Blanchard to groundnut. *Indian J. agric. Sci.* 51: 466.

BRAR, K.S. and SANDHU, G. S. 1982. Field biology of the white grub, *Holotrichia consanguinea* Blanchard (Scarabaeidae : Coleoptera) in Punjab. *J. Soil Biol. Ecol.* 2: 32-35.

BUCKLE, P. 1921. A preliminary survey of the soil fauna of agricultural land. *Ann. Appl. Biol.* 8: 135-145.

CHANNA BASAVANNA, G.P. 1981. Contributions to acarology in India. The Acarological

Society of India, UAS, Bangalore, pp. 1-256

CHHABRA, K.S. 1981. Incidence of termites on pulses in Punjab—a survey report. *Progress in Soil Biology and Ecology in India.* (ed.) G.K. Veeresh, U.A.S. Tech. Series. 37: 278-280.

CHHOTANI, O.B. 1980. Termite pests of agriculture in Indian region and their control. *Zool. Surv. India, Tech. Monogr.*, No. 4, pp. 1-94.

CHHOTANI, O.B. 1981. Soil termites of India. *Progress in Soil Biology and Ecology in India.* (ed.) G.K. Veeresh, U.A.S. Tech. Series. 37: 229-236.

CHOUDHURI, D.K. 1960. Influence of temperature on the development of *Onychiurus furciferus* and its mathematical representation. *Proc. Zool. Soc. Calcutta* 13 : 123-128.

CHOUDHURI, D.K. 1961. Influence of temperature on sex ratio of *Onychiurus imperfectus* Davis. *Sci. & Cult.* 27: 48-49.

CHOUDHURI, D.K. 1963. Effects of some physical factors on the genus *Onychiurus* (Collembola). *Proc. natl. Acad. Sci. India* 33: 538-546.

CHOUDHURI, D. K. and BANERJEE, S. 1975. Qualitative and quantitative composition of Acari and Collembola in relation to soil organic matter microbes complex. *Oriental Insects* 9: 313-316.

CHOUDHURI, D.K. and BANERJEE, S. 1977. Soil factors and oribatid mites under conditions of West Bengal. *The Univ. Burdwan Publ.* pp 1-88.

CHOUDHURI, D.K. and PANDE, T. 1979. High altitude soil animals and their relation with soil factors, with special reference to mites. *Rev. Ecol. Biol. Sol.* 16: 219-226.

CHOUDHURI, D.K. and PANDE, T. 1981. Studies on the population and distribution of high altitude soil Acarines in relation to different soil factors. *Contribution to Acarology in India,* (ed.) G.P. Channa Basavanna, A.S.I., Bangalore, pp. 147-154.

CHOUDHURI, D K. and ROY, S. 1966. The role of edaphic factors on the distribution of subterranean Collembola fauna of West Bengal. *Part I., Monografias Prog. in Biol. del Suelo Actas Uel Primer Coloquio Latin Americano de Biologia del Suelo* pp. 391-403.

CHOUDHURI, D.K. and ROY, S. 1967. Qualitative composition of Collembola fauna of some cultivated fields in Nadia District (West Bengal) with a correlation between monthly population and individual soil factors. *Rev. Ecol. Biol. Sol.* 3: 507-515.

CHOUDHURI, D.K. and ROY, S. 1970. Interaction between soil Collembola and other subterranean arthropods. *Sci. & Cult.* 36: 280-282.

CHOUDHURI, D. K. and ROY, S. 1971 a. The Collembola (Insecta) of the uncultivated fields in Burdwan district (West Bengal), with remarks and correlation between monthly population and certain soil factors. *Proc. Zool. Soc. Calcutta* 24 : 33-39.

CHOUDHURI, D.K. and ROY, S. 1971b. Seasonal fluctuation and vertical distribution of the genus *Lepidocyrtus* (Collembola :

Insecta) in some uncultivated fields of Gangetic West Bengal, India. *Rev. Ecol. Biol. Sol.* 8: 253-259.

CHOUDHURI, D.K. and ROY, S. 1971 c. Distribution of Collembola in relation to soil conditions in the district of Jalpaiguri, West Bengal (India). *Organisms du Sol et Production Primaire, Proc. IV Coll., Pedobiologiae*, INRA, Paris, pp. 289-296.

CHOUDHURI, D.K. and ROY, S. 1972. An ecological study on Collembola of West Bengal (India). *Rec. Zool. Sur. India* 66: 81-101.

CHOUDHURI, D.K., HAZRA, A.K. and ROY, S. 1978. Soil factors governing the distribution of Collembola (Insecta) in the graveyard of Berhampore, Murshidabad district (West Bengal). *Soil Biology and Ecology in India.* (eds.) C.A. Edwards & G.K. Veeresh, UAS Tech. Series. 22: 161-172.

DARLONG, V.T. and ALFRED, J.R.B. 1982. Differences in arthropod population structure in soils of forest and jhum sites of North Eastern India. *Pedobiologia* 23: 112-119.

DAS, S.R., MAHESHWARI, K L., NIGAM, S. S., SHUKLA, R.K. and TANDON, R.N. 1962. Microorganisms from the fungus garden of the termite *Odontotermes obesus* (Rambur). In: *Termites in the Humid Tropics* (ed.) M.L. Roonwal, *Proc. New Delhi Symposium, UNESCO, Paris*, pp. 163-166.

DAVID, H. 1978. Soil arthropod pests of sugarcane in Tamil Nadu and their control. *Soil Biology and Ecology in India*, (eds.) C.A. Edwards & G.K. Veeresh, UAS Tech. Series. 22: 244-249.

DAVID, H. and ALEXANDER, K.C. 1975. Natural occurrence of milky disease bacterium, *Bacillus popilliae* Dutky on white grub in India. *Curr. Sci.* 44: 819-820.

DAVID, H. and ANANTHANARAYANA, K. 1974. Some aspects of the biology of white grub in sugarcane in Tamil Nadu. *Whitegrub Newsletter* 1: 11-15.

DESAI, M.T. and PATEL, R.M. 1965. Some observations on the biology and control of white grub in soil (*Holotrichia consanguinea* Blanch.). *Indian J. Entomol.* 27: 89-94.

DHAR, S., RAINA, M.K. and KACHROO, P. 1981. An ecological study of microarthropods of a coniferous forest of Kashmir Himalayas. *Sci.& Cult.* 47: 327-329.

DUTTA, A.K. 1983. Studies on ground beetles (Coleoptera : Insecta) of Dooars area, Jalpaiguri, West Bengal with special reference to their taxonomy, seasonal activity and density by pit-fall experiment. Ph.D. Thesis, University of North Bengal Darjeeling.

DUTTA, A.K. and GUPTA, T.S. 1981. Seasonal activity and population density of ground dwelling beetles of Dooars area, West Bengal. *Progress in Soil Biology and Ecology in India.* (ed.) G K. Veeresh, UAS Tech. Series. 37: 178-180.

EDWARDS, C.A. 1974. Macroarthropods. *Biology of Plant Litter Decomposition,* (eds.) C.H. Dickinson & G J.F. Pugh, Academic Press, London & New York, pp. 533-554.

EDWARDS, C.A. and FLETCHR, K.E. 1971. A comparison of the extraction methods for

terrestrial arthropods. *Methods of Study in Quntitative Soil Zoology: Population, Production and Energy Flow*, (ed.) J. Phillipson, Blackwell, Oxford.

GEORGE, A. and PRABHOO, N.R. 1981. Some aspects of biology of the pseudoscorpion, *Lagynochthonius hygricus* (Chthoniidae : Chelonethi). *Progress in Soil Biology and Ecology in India*, (ed.) G.K. Veeresh, UAS Tech. Series. 37: 114-119.

GHATAK, T.K. and ROY, S. 1981. Acarina fauna of a cultivated field of Hoogly district, West Bengal. In: *Contributions to Acarology in India*, (ed.) G.P. Channa Basavanna, Acarological Society of India. Banglore, pp. 24-28.

GHOSH, A.K. 1981. Ecology of subterranean aphids (Homoptera : Insecta) in India. (ed). S.K. Veersh, UAS Tech. Series. 37: 223-228.

GILYAROV, M. S. 1949. Besonderheiten des Bodens als Labensraum und dessen Bedeutung in der Entwicklung der insekten. *Verlag. Acad. Wiss. S.S.S.R.*, pp. 279.

GOKHALE, N.G., SARMA, S.N., BHATTACHARYA, N.G. and DUTTA, J.S. 1958. Effect of termite activity on the chemical properties of tea soils. *Sci. & Cult.* 24: 229.

GUPTA, C.S. 1963. Ecological studies on *Componotus compressus* Fabr. (Formicidae : Hymenoptera). *Agra Univ. J. Res. (Sci.)* 12: 45-52.

GUPTA, C. S. 1964. Studies on ecology and population pattern of *Oecophylla smaragdina* Fabr. (Formicidae : Hymenoptera) during spring in Hardwar. *Agra Univ. J. Res. (Sci.)* 13: 59-66.

GUPTA, C.S. 1968. Studies on the effect of light, wind and moisture on *Oecophylla smaragdina* Fabr. *Trop. Ecol.* 9: 131-139.

GUPTA, G. P. and MUKHERJI, S. P. 1976 a. Microarthropods in some cultivated soil at Varanasi. *Indian J. Entomol.* 38: 272-280.

GUPTA, G. P. and MUKHERJI, S. P. 1976 b. Qualitative composition of fauna of cultivated and uncultivated soil. *Ibid.* 38 : 313-324.

GUPTA, S.D. 1952. Ecological studies of termites Part I.—Population of the mound building termite, *Odontotermes obesus* (Rambur) (Isoptera: Termitidae). *Proc. Natn. Inst. Sci. India, New Delhi (B)* 19: 697-704.

GUPTA, S.R. and SINGH, J.S. 1977. Decomposition of litter in a tropical grassland. *Pedobiologia* 17: 330-333.

GUPTA, S R., RAJVANSHI, R. and SINGH, J.S. 1981. The role of the termite, *Odontotermes gurdaspurensis* (Isoptera: Termitidae) in plant decomposition in a tropical grassland. *Ibid.* 22: 254-261.

HAQ, M.A. and PRABHOO, N.R. 1976. Observations on the feeding habits of oribatid mites from soils of Kerala (Acarina: Cryptostigmata)—Panphytophages. *Entomon* 1: 133-137.

HARDING, D J.L. and STUTTARD, R. A. 1974. Microarthropods. *Biology of Plant Litter Decomposition*, (eds.) C.H. Dickinson & G.J F. Pugh, Academic Press, London & New York, pp. 489-532.

HAZRA, A.K. 1976. The influence of soil factors on the distribution of Collembolan fauna

in cultivated and uncultivated fields of West Bengal. D. Phil. Thesis, Burdwan University, Burdwan.

HAZRA, A.K 1978 a. Effects of organic matter and water content of soil on the distribution of Collembola (Insecta) in an uncultivated field of West Bengal. *Bull. Zool. Surv. India* 1: 107-114.

HAZRA, A.K. 1978 b. Ecology of Collembola in a deciduous forest floor of Birbhum district, West Bengal in relation to soil moisture. *Oriental Insects* 12: 265-274.

HAZRA, A.K. 1982. Soil and litter arthropod fauna of Silent Valley, Kerala: A preliminary report. *J. Soil Biol. Ecol.* 2: 73-77.

HAZRA, A K. and CHOUDHURI, D. K. 1981. Studies on the distribution of Collembola population in two different soil conditions (Gangetic alluvium and laterite soil) in relation to some major edaphic factors. In: *Progress in Soil Biology and Ecology in India*, (ed.) G.K. Veeresh, UAS Tech. Series. 37: 131-142.

HAZRA, A.K. and CHOUDHURI, D.K. 1983. A study of Collembola of West Bengal in relation to 3 major soil factors. *Rev. Ecol. Biol. Sol.* 20: 385-402.

HAZRA, A.K., CHOUDHURI, D.K. and ROY, S. 1976. Influence of soil pH on the Collembolan fauna of two uncultivated fields of Gangetic West Bengal. *J. Biol. Sci.* 19: 19-24.

HOLE, F. 1981. Effects of animals on soil. *Geoderma* 25: 75-112.

JAYARAMAIAH, M. and VEERESH, G. K. 1978. Soil-inhabiting beneficial insects (predators and parasites of insects) in India: a brief review. In: *Soil Biology and Ecology in India*, (eds.) C.A. Edwards & G.K. Veeresh, UAS Tech. Series. 22: 223-226.

JOSEPH, K.J. 1978. Termites and soil. *Ibid.* 22: 186-191.

JOY, S. and BHATTACHARYA, T. 1981 a. Cryptostigmatid population of the soil of a banana plantation in relation to some edaphic factors. In: *Progress in Soil Biology and Ecology in India*, (ed.) G. K. Veeresh, UAS Tech. Series. 37: 100-107.

JOY, V.C. and BHATTACHARYA, T. 1981 b. A comparative assessment of the effect of some herbicides on the microarthropods of cultivated soil. *Ibid.* 37: 299-304.

KEVAN, D.K. MCE. 1965. The soil fauna—its nature and biology. In: *Ecology of Soil-borne Plant Pathogens, Prelude to Biological Control*, (ed.) K.F. Baker, University of California Press, Berkeley, California, pp. 33-51.

KUHNELT, W. 1963. Soil inhabiting arthropoda. *Annu. Rev. Entomol.* 8: 115-136.

KUMAR, K. and AGARWAL, R.A. 1983. Systemic granular insecticides and rhizosphere fauna of cotton. *J. Soil Biol. Ecol.* 3: 13-21.

KUNDU, H.L., DATTAGUPTA, A.K. and GUPTA, B.B. 1961. A study of abundance of certain insects of Pilani with the help of light traps. *Proc. Rajasthan Acad. Sci.* 8: 79-87.

KURUP, N.C. and PRABHOO, N.R. 1982. Influence of food quality on reproduction and longevity of *Cryptopygus thermophilus* (Isotomidae : Collembola). *Entomon* 7: 481-485.

MANI, M.S. and SINGH, S. 1955. Entomological survey of Himalayas, Part XIII. Second entomological expedition to the North West (Punjab) Himalaya (1955). *Agra Univ. J. Res.* (*Sci.*), 4 (Suppl.): 717-739.

MATHUR, Y.K., NIGAM, P.M. and SRIVASTVA, J.P. 1979. Bionomics of white grub. 1. Life and seasonal history—*Holotrichia consanguinea* Blanch. *Natl. Symp. on White grub, C.S.A. Univ. Agric. & Tech., Kanpur*, pp. 19-20.

MINDERMAN, G. 1957. The preparation of microtome sections of unaltered soil for the study of soil organisms *in situ*. *Plant & Soil* 8: 42-48.

MITRA, S.K., HAZRA, A.K. and SANYAL, A K. 1977. Ecology of Collembola at the Eden gardens, Calcutta. *Ecol. Bull.* (*Stockholm*), 25: 539-544.

MITRA, S.K., HAZRA, A.K. and SANYAL, A.K. 1978. Distribution of Collembola in accordance with different vegetation at Eden Gardens, Calcutta. In: *Soil Bology and Ecology in India*, (eds.) C A. Edwards & G.K. Veeresh, UAS Tech. Series. 22: 152-156.

MITRA, S.K., HAZRA, A.K., SANYAL, A.K. and MANDAL, S.B. 1981. Changes in the population structure of Collembola and Acarina in a grassland ecosystem at Calcutta. In: *Progress in Soil Biology and Ecology in India*, (ed.) G K. Veeresh, UAS Tech. Series. 37: 143-146.

MUKHERJEE, P. and ROY, S. 1981. Collembola community in two contrasting environments of West Bengal. *Ibid.* 37: 126-130.

MUKHERJI, D. and MITRA, P.K. 1949. Ecology of the mound building termites, *Odontotermes redemanni* (W.) in relation to measures of control. *Proc. Zool. Soc. Bengal* 2: 9-26.

MUKHARJI, S.P. and SINGH, J. 1967. Some aspects of study of soil arthropods in the wheat field and floral garden. *J. Sci. Res., B.H.U.* 2: 177-185.

MUKHARJI, S.P. and SINGH, J. 1970. Seasonal variations in the densities of a soil arthropod population in a rose garden at Varanasi (India). *Pedobiologia* 10: 442-446.

MURALEEDHARAN, V. and PRABHOO, N.R. 1978. Observations on the feeding habits of some soil Collembola from an abandoned field in Kerala. *Entomon* 3: 207-213.

NICHOLAS, D P. and PARKINSON, D. 1967. A comparison of methods for assessing the amount of fungal mycelium in soil samples. *Pedobiologia* 7: 23-41.

O'CONNER, F.B. 1957. An ecological study of the Enchytraeid worm population of a coniferous forest soil. *Oikos* 8: 162-199.

OMODEO, P., MINELLI, A. and BACCETTI, B. 1980. On the phylogeny of pterygote insects. *Boll. Zool.* 47 (Suppl.): 49-63.

OPPENHEIMER, J.R. and TIKADER, B.K. 1976. The ground activity of spiders (Araneae) and harvestmen (Phalangidae) in West Bengal, India. *J. Bombay nat. Hist. Soc.* 73: 121-141.

OWEN, D.F. and WIEGERT, R G. 1976. Do consumers maximise plant fitness ? *Oikos* 27: 488-492.

PAI, C.G.A. and PRABHOO, N.R. 1980. Microarthropods associated with post-harvest decay of paddy tillers in Kerala. In: *Wetlands*:

Ecology and Management, *Proc. 1st Intern. Wet. Conf.* (eds.) B. Gopal, R.E Turner, R.G. Wetzel & D F. Whigham, Intern. Sci. Publ., Jaipur, pp. 123-129.

PAI, C.G.A. and PRABHOO, N.R 1981. Preliminary observations on the microarthropod fauna of paddy fields and adjoining uncultivated soil in South Kerala In: *Progress in Soil Biology and Ecology in India*, (ed.) G. K. Veeresh, UAS Tech. Series 37: 27-32.

PAL, S K. 1977. White grubs and their management. *CAZRI Jodhpur, Monograph No.* 5, pp. 1-36.

PANDE, Y.D. 1975. Scope of the gelatine-embedding technique for studying soil arthropod fauna with particular reference to Oribatei In: *Progress in Soil Zoology, Proc. 5th Intern. Coll. Soil. Zool* (ed) J. Vanek, Dr. W. Junk, B.V. Publ., The Hague and Academia, Prague pp. 547-558.

PATHAK, A.N. and LEHRI, L.K. 1959. Studies on termite nests. I. Chemical, physical and biological characteristics of a termitarium in relation to its surroundings. *J Indian Soc. Soil Sci* 7: 87-90.

PATIL, B.V., DEVAIAH, M.C. and THONTADARYA, T.S. 1981. Phototrophic soil inhabiting insect pest fauna of Dharwad region as revealed by a mercury bulb light-trap. In: *Progress in Soil Biology and Ecology in India*. (ed.) G.K. Veeresh, UAS Tech. Series. 37: 187-192.

PATIL, R B., GODSE. D.B. and KULKARNI, J.H. 1978. Soil microbes and their interaction with soil invertebrates. In: *Soil Biology and Ecology in India*. (eds.) C.A. Edwards & G.K. Veeresh, UAS Tech. Series. 22: 9-16.

PILLAI, K.S. and SINGH, J. 1980. The composition of soil microarthropods in a grassland ecosystem of Upper Gangetic plain. *Proc. Symp. Environ. Biol.* Trivandrum, pp. 24-34.

PRABHOO. N.R. 1976. Soil microarthropods of a virgin forest and adjoining tea fields in the Western Ghats in Kerala—a brief ecological study. *Oriental Insects* 10: 435-442.

PRABHOO, N.R. 1981. Trends of progress in studies on the biology and ecology of soil insects in India—a brief review. In: *Recent Advances in Entomol, India*, (ed.) T. N. Ananthakrishnan, Viswanathan Publ., Madras, pp. 49-60.

PRASAD, V. 1965. Soil mites of Sabour (Bhagalpur). *Sci. & Cult.* 31: 495-496.

PRICE, D. W. 1973. Abundance and vertical distribution of microarthropods in the surface layers of California pine forest soil *Hilgardia* 42: 121-148.

RAINA. M.K., KACHROO, P. and DHAR, S. 1979. Soil and litter mesofauna from Kashmir Himalayas. *Geobios* 6: 329-330.

RAJAGOPAL. D. and VEERESH, G. K. 1981. Foraging activity of the mound building termite, *Odontotermes wallonensis* (Wasmann) (Isoptera: Termitidae). *J. Soil Biol. Ecol.* 1: 56-64.

RAJAGOPAL, D., SATYANARAYANA, T. and VEERESH, G. K. 1982. Physical and chemical properties of termite mound and surrounding soil of Karnataka. *Ibid.* 2: 18-31.

RANGANATHAIAH, K. G., VEERESH, G. K. and GOVINDU, H.C. 1973. A new entomogen-

ous fungus on the root grub, *Holotrichia serrata* F. from Mysore. *Curr. Sci.* 42: 432-433.

REDDY, A.S., KUMAR, R. and MATHUR, S. N. 1978. Studies on the biology of *Galumna flabellifera* Hammer, 1958 and its role as fungal spore carrier. In: *Soil Biology and Ecology in India*, (eds.) C.A. Edwards & G. K. Veeresh, UAS Tech. Series. 22: 134-143.

REDDY, M.V. 1979. Workshop on soil microarthropods. *Pedobiologia* 19: 161-162.

REDDY, M. V. 1980 a. Epigeic activities of *Dicranocentroides cf. salmoni* (Paronellinae: Entomobryidae). *Geobios* 7: 208.

REDDY, M.V. 1980 b. Arthropod faunal structure of soil surface understone habitats at Berhampur, Orissa. *Newsletter of Soil Biology & Ecology* 1: 18-19.

REDDY, M.V. 1981 a. Microarthropods and the rate of needle litter disappearance in pine plantation ecosystem of North Eastern India. *Pedobiologia* 22: 339-344.

REDDY, M.V. 1981 b. Ecological observations on the seasonal abundance and excavating activity of a field cricket, *Brachytrupes portentosus* Licht. (Orthoptera: Gryllidae). *J. Soil Biol. Ecol.* 1: 42-46.

REDDY, M.V. 1981 c. Faunal composition of soil microarthropods of tea nursery beds at Nayabungalow, North Eastern India. *Indian J. Ecol.* 8: 108-111.

REDDY, M.V. 1981 d. The role of Acarina in edaphic ecosystem. In: *Contribution to Acarology in India*. (ed.) G.P. Channa Basavanna, *Acarological Society of India, Bangalore*, pp. 158-166.

REDDY, M.V. 1983 a. The effect of controlled burning on the edaphic microarthropod population densities in a pine, *Pinus khasiya* Royle plantation. *J. Environ. Biol.* 4: 149-153.

REDDY, M.V. 1983 b. The enigma of the influence of abiotic environment on the arthropod abundance. In: *Notes and discussion on Symposia (Focal theme), Section of Zoology, Entomology and Fisheries* I.S.C.A., 70th Session, pp. 7-8.

REDDY, M.V. and ALFRED, J.R.B. 1978. Microarthropods associated in the decomposition process of needle litter of Meghalaya pine (*Pinus khasiya* Royle) forest. In: *Soil Biology and Ecology in India*, (eds.) C.A. Edwards & G K. Veeresh, UAS, Tech. Series. 22: 236-243.

REDDY, M. V. and ALFRED, J.R.B. 1982. On the seasonal relative abundance of insect consumer population in a pine (*Pinus khasiya* Royle) forest ecosystem of North Eastern India. *Proc. Symp. Ecol. Anim. Popul. Zool. Surv. India, Pt.* 3: 107-117.

REDDY, M.V. and DAS, P.K. 1983. Microfungal food preference of soil microarthropods in a pine plantation ecosystem. *J. Soil Biol. Ecol.* 3: 1-6.

REDDY, M.V. and SHARMA, G.D. 1981. Some observations on an aphid mycorrhizal association. *Sci. & Cult.* 47: 339-340.

REDDY, M.V. and VERMA, N.K. 1981. Aphid mycorrhizal association and its relationship with rhizosphere soil pH. *Comp. Physiol. & Ecol.* 6: 157-158.

ROONWAL, M.L. 1954. Biology and ecology of oriental termites (Isoptera). No. 2. On

ecological adjustment in nature between two species of termites namely *Coptotermes heimi* (Wasmann) and *Odontotermes redemanni* (Wasmann) in Madhya Pradesh, India. *J. Bombay nat. Hist. Soc.* 52: 463-467.

ROONWAL, M.L. 1958. Recent work on termite research in India (1947-57). *Trans. Bose Res. Inst. Calcutta* 22: 77-100.

ROONWAL, M.L. 1972. Aspects of the ecology and control of wood borers and termites: A review of recent work in India. *J. Indian Acad. Wood Sci.* 3: 24-33.

ROONWAL,M.L. 1979. *Termite Life and Termite Control in Tropical South Asia.* Scientific Publishers, Jodhpur.

ROONWAL, M.L. 1981. Termites of agricultural importance in India and their control. In: *Progress in Soil Biology and Ecology in India*, (ed.) G. K. Veeresh, UAS Tech. Series. 37: 253-265.

SAMRA, J.S., TANDON, P.L., THAKUR, R.S. and CHADHA, K. L. 1979. Comparison of physico-chemical characteristics of the soils of termite galleries and the surrounding soil in mango orchards. *Indian J. agric. Sci.* 49: 892-895.

SANYAL, A.K. 1981 a. Qualitative and quantitative composition of oribatei in Gangetic delta of West Bengal in relation to edaphic factors. *Bull. Zool. Surv. India* 4: 295-307.

SANYAL, A.K. 1981 b. Ecology of soil oribatid mites in an uncultivated field of Gangetic delta of West Bengal in relation to soil pH and salinity. In: *Progress in Soil Biology and Ecology in India*, (ed.) G K. Veeresh, UAS Tech. Series. 37: 107-112.

SANYAL, A.K. 1982. Soil oribatid mites and their relation with soil factors in West Bengal. *J. Soil Biol. Ecol.* 2: 8-17.

SANYAL, A.K. and BHADURI, A.K. 1982. Seasonal changes in the density of soil oribatid mites in relation to temperature and water content of soil at Sagar Island, 24 Parganas, West Bengal. *Proc. Symp. Ecol. Anim. Popul. Zool. Surv. India Pt.* 3: 119-126.

SEN, A. 1944. The influence of feed upon the composition of termite soils. *Curr. Sci.* 13: 280-281.

SENGUPTA, R. 1981. Soil fauna and insecticides interactions. In: *Progress in Soil Biology and Ecology in India*, (ed.) G.K. Veeresh, UAS Tech. Series. 37: 324-328.

SEN-SARMA, P.K. 1962. Some observations on swarming in nature and colony foundation under laboratory conditions in *Odontotermes assmuthi* (Holmgren) at Dehra Dun. *Beitr. Entomol.* 12: 292-297.

SEN-SARMA, P.K. 1964. The effects of temperature and relative humidity on the longevity of pseudo workers of *Kalotermes flavicollis* (Fabr.) (Isoptera) under starvation conditions. *Proc. Natn. Inst. Sci. India*, (*B*), 30: 300-314.

SEN-SARMA, P.K. 1974. Ecology and biogeogr-aphy of the termites of India. In: *Ecology and Biogeography in India.* (ed.) M. S. Mani, Dr. W. Junk Publ., Hague, pp. 421-472.

SEN-SARMA, P. K. 1981. Recent advances in termite research in India and future strategy. In: *Progress in Soil Biology and Ecology in India*, (ed.) G. K. Veeresh, UAS Tech. Series. 37: 236-253.

SEN-SARMA, P.K. and CHATTERJEE, P.N. 1966. Humidity behaviour of termites. 1. Effect of relative humidity on the longevity of workers of *Microcerotermes beesoni* Snyder (Insecta: Isoptera : Termitidae) under starvation conditions. *Indian For. Bull.* (N.S.) (Ent.) 255: 1-6.

SEN-SARMA, P.K. and MISHRA, S.C. 1969. Seasonal variations of nest population in *Microcerotermes beesoni* Snyder. *Proc. Natn. Inst. Sci. India* (*B*) 36: 361-367.

SEN-SARMA, P.K. and MISHRA, S.C. 1972. Seasonal fluctuation of colony composition and population in *Neotermes bosei* Snyder (Insecta; Isoptera; Kalotermitidae) *J. Indian Acad. Wood Sci* 3: 43-48.

SEN-SARMA, P. K. and MISHRA, S C. 1981. Fluctuation of brood population in termite colony (Insecta: Isoptera). *J. Soil Biol. Ecol.* 1: 47-55.

SHARMA, S K. and BHORA, O.P. 1968. A new record of *Dorylus labiatus* Shuck (Hymenoptera : Formicidae) as a predator of *Microtermes mycophagus* (Isoptera: Termitidae). *Indian J. Entomol.* 30: 243.

SHARMA, S.K., SINGH, V. and VIJAYVERGIA, J. 1981. Population density of grubs of *Holotrichia consanguinea* in relation to different host plants and space. In: *Progress in Soil Biology and Ecology in India*, (ed.) G.K. Veeresh, UAS Tech. Series. 37: 171-172.

SHRIKHANDE, J.G. and PATHAK, A. N. 1948. Earthworms and insects in relation to soil fertility. *Curr. Sci.* 17: 327-328.

SHRIKHANDE, J.G. and PATHAK, A.N. 1951. A comparative study of the physico-chemical characters of castings of different insects. *Indian J. agric. Sci.* 21: 401-408.

SINGH, J. 1975. The efficiency of collecting soil arthropods from the froth by floatation method at different intervals of counting. In: *Progress in Soil Zoology, Proc. 5th Intern. Coll. Soil Zool.* (ed.) J. Vanek. Dr. W. Junk, The Hague and Academia, Prague, pp. 599-602.

SINGH, J. 1978. Soil fauna studies in India. In: *Soil Biology and Ecology in India*, (eds.) C.A. Edwards & G.K. Veeresh, UAS Tech. Series. 22: 226 235.

SINGH, J. and MAHAJAN, S.V. 1983. Community structure and biocoenology of soil microarthropods in a tropical deciduous forest soil at Varanasi (India). In: *Insect Interrelations in Forest and Agroecosystems*.(eds.) P.K. Sen-Sarma, S.R. Sangal and S.K. Kulshreshtha, Juggal Kishore, Dehra Dun, pp. 209-217.

SINGH, J. and MUKHARJI, S.P. 1971. Qualitative composition of soil microarthropods in some fields at Varanasi (Insecta). *Oriental Insects* 5: 487-494.

SINGH, J. and MUKHERJI, S.P. 1973. Population size of soil arthropods in some fields at Varanasi (India). *Sci. & Cult.* 39: 498-500.

SINGH, J. and PILLAI, K.S. 1975. A study of soil microarthropod communities in some fields. *Rev. Ecol. Biol. Sol.* 12: 579-590.

SINGH, J. and PILLAI, K.S. 1976. The use of floatation method in the collection of microarthropods from arable soil in India. *Ibid.* 13: 331-335.

SINGH, J. and PILLAI, K.S. 1981. Community structure and biocoenology of soil microarthropods in some tropical fields at Varanasi, India. *J. Soil Biol. Ecol.* 1: 5-20.

SINGH, J. and SINGH, U.R. 1975. An ecological study of soil microarthropods from soil and litter of tropical deciduous forest of Varanasi (India). *Trop. Ecol.* 16: 81-85.

SINGH, J.S. and GUPTA, S.R. 1977. Plant decomposition and soil respiration in terrestrial ecosystems. *Bot. Rev.* 43: 449-528.

SINGH, J S. and YADAV, P.S. 1973. Caloric values of plant and insect species of a tropical grassland. *Oikos* 24: 186-194.

SINGH, U R. 1975. A correlation study between Collembola population and moisture gradient at Varanasi forest, India. *Int. J. Ecol. Environ. Sci.* 1: 179-180.

SINGH, U.R. 1977. Relationship between the population density of soil microarthropods and mycoflora associated with litter and total litter respiration on the floor of a sal forest in Varanasi, India. *Soil Organisms as Components of Ecosystems. Ecol. Bull.* (*Stockholm*) 25: 463-470.

SINGH, U R. 1979. Caloric values and mineral contents of some insects of different trophic levels. *Indian J. Entomol.* 41:379-384.

SINGH, U.R. and SHUKLA, A.N. 1977. Soil respiration in relation to mesofaunal and mycofloral population during rapid course of decomposition on floor of a tropical dry deciduous forest. *Rev. Ecol. Biol. Sol.* 14: 363-370.

SINGH, U.R. and SINGH, A.K. 1975. A preliminary quantitative report of soil microarthropods from the floor of a Himalayan grassland biome. *Intern. J. Ecol. Environ. Sci.* 1: 175-177.

SINGH, U.R. and SINGH, J.S. 1981 a. Population structure and mound architecture of the termites of a tropical deciduous forest of Varanasi, India. *Pedobiologia* 22: 213-223.

SINGH, U.R. and SINGH, J.S. 1981 b. Temperature and humidity relations of termites. *Ibid* 21: 211-216.

SINGH, U.R. and TRIPATHI, B.D. 1978. Effect of industrial effluents on the population density of soil microarthropods. *Environ. Conserv.* 5: 229-231.

SINGH, U.R., PANDEY, P.N. and TRIPATHI, B.D. 1979. Ecophysiology of polluted pedoecosystem with special reference to its mesofaunal composition. *Indian J. Ecol.* 6: 53-60.

SINGH, U.R., SINGH, J. and SINGH, I D. 1978. Microbial association with termites in a tropical deciduous forest at Varanasi. *Trop. Ecol.* 19: 163-173.

SOUTHWOOD, T.R E. 1966. *Ecological Methods with particular reference to the Study of Insect population.* Methuen & Co. Ltd., London.

SUKHIJA, H.S, BAKHETIA, D.R.C. and BRAR, R.S. 1981. Studies on white grub *Holotrichia consaguinea* in the Punjab. 1. Biology, behaviour and control of beetles. In: *Progress in Soil Biology and Ecology in India,* (ed.) G.K. Veeresh, UAS Tech. Series. 37: 164-170.

TREHAN, K.N. 1945. Some observations of the soil fauna of cotton field at Lyalpur. *Proc. Indian Acad. Sci. Sect. B.* 21: 191-201.

USHER, M.B., BOOTH, R G. and SPARKES, K.E. 1982.A review of progress in understanding the organisation of communities of soil arthropods *Pedobiologia* 23: 126-144

UVAROV, B. P. 1931. Insects and climate. *Trans. R. ent. Soc.* 79: 1-247.

VAISHAMPAYAN,S.M. 1981. Light trap studies on black cutworm, *Agrotis ipsilon*. In: *Progress in Soil Biology and Ecology in India*. (ed.) G.K. Veeresh, UAS Tech. Series. 37: 192-200.

VAISHAMPAYAN, S. M. and VEDA, O.P. 1981. Studies on chemical control of black cutworm, *Agrotis ipsilon*, a serious pest of wheat and gram around Jabalpur. *Ibid.* 37: 306-313.

VATSAULIYA, P.K. and ALFRED, J.R.B. 1980. Quntitative study of the soil arthropod in Jhum ecosystems of North Eastern India. *The Indian Zoologist* 4: 153-160.

VEENAKUMARI, K. and Veeresh, G.K. 1982. Evaluation of different methods of inoculation for the production of the milky white disease caused by the bacterium, *Bacillus popilleae* Dutky on the white grub, *Holotrichia serrata* Fabr. *J. Soil Biol. Ecol.* 2: 1-7.

VEERANNA, G. and BASALINGAPPA, S. 1981. Foraging behaviour of the termite, *Odontotermes wallonensis* Wasmann (Isoptera : Termitidae). *The Indian Zoologist* 5: 5-9.

VEERESH, G.K. 1977. *Studies on the Root Grubs in Karnataka*. UAS Monograph series. 2: 1-87.

VEERESH, G.K. 1981. Progress in soil biology and ecology in India. UAS Tech. Series. 37: 1-351.

VEERESH, G.K. and EDWARDS, C.A. 1978. Soil biology and ecology in India. UAS Tech. Series. 22: 1-344.

VEERESH, G K. and RAJANNA, C. 1981. Seasonal activity of Scarabaids as evidenced by light trap catches. In: *Progress in Soil Biology and Ecology in India*. (ed.) G. K. Veeresh, UAS Tech. Series. 37: 153-158.

VEERESH, G K. and REDDY, N.V.M. 1978. Preliminary observations of soil fauna of grassland and cultivated soil of Hebbal, Bangalore. *Newsletter Soil Biology & Ecology* 1: 7-8.

VEERESH, G. K., VEERARAJU, P. V., GUBBAIAH, and REDDY, N.V.M. 1978. Efficacy of certain soil insecticides against root grub (*Holotrichia serrata* F.) under different conditions of cultivation. In: *Soil Biology and Ecology in India*. (eds.) C.A. Edwards & G. K. Veeresh, UAS Tech. Series. 22: 326-333.

VERGHESE, A. and VEERESH, G.K. 1978. Ants of India—a brief review. *Ibid.* 22: 172-181.

VERMA, A. N., BHANOT, J. P. and KHURANA, A.D. 1981. Effect of crop rotation on termite damage and yield of wheat crop. *Progress in Soil Biology and Ecology in India*. (ed.) G K. Veeresh, UAS Tech. Series. 37: 291-294.

VISWANATH, B.N., GOVINDAN, R. and RANGASWAMY, H.R. 1978. Moisture as an essential factor for the survival of *Polytus mellarborgii* (Boheman) (Coleoptera: Curculionidae). In: *Soil Biology and Ecology in India*. (eds.) C.A. Edwards & G.K. Veeresh, UAS Tech. Series. 22: 254-255.

VYAS, H.K., MANGROLA, J. P. and SINGH, B. 1981. Investigations on white grubs infesting sugarcane. *Progress in Soil Biology and Ecology in India.* (ed.) G.K. Veeresh, UAS Tech. Series. 37: 159-161.

YADAVA, C.P.S., MISHRA, R.K. and SAXENA, R.C. 1978. Ecological studies on white grub *Holotrichia consanguinea* Balch. *Soil Biology and Ecology in India.* (eds.) C.A. Edwards & G.K. Veeresh, UAS Tech. Series. 22: 209-216.

YADAVA, C.P.S., SAXENA, R.C., MISHRA, R.K. and DADEECH, L. N. 1977. Population management of white grub, *Holotrichia consanguinea* Blanch. in an agroecosystem. *Indian J. Entomol.* 29: 205-210.